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Unsafe human behavior at construction sites

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Unsafe human behavior at construction sites

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Editorial: Unsafe human behavior at construction sites

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Editorial on the Research Topic
Unsafe human behavior at construction sites

Overview of research contents

Based on the analysis of the papers collected by the special journal, it is found that most scholars like to explore the complex influencing factors of unsafe behaviors on the construction site and their action paths to unsafe behaviors. For example, Ni et al. used grounded theory and system dynamics to explore the formation mechanism and dynamic evolution of unsafe behaviors of the new generation of construction workers in China's construction industry. Qie and Yan discussed the complex influencing factors and action paths of unsafe accidents in subway construction sites. Li P et al. used a latent Dirichlet (LDA) assignment model to identify the unsafe behaviors of construction workers and their influencing factors, and then, with the help of social network analysis, determined the importance of the influencing factors and their relationships. Zhou et al. analyze the motives of core enterprises to participate in safety management in supply chain from a behavioral perspective by using in-depth interviews and grounded theory, that is, the internal and external influencing factors of core enterprises' work safety management behaviors in supply chain and their mechanisms on enterprise management behavior decisions are explored in depth from a microscopic perspective.

In addition, some scholars also like to explore the mechanism of unsafe behaviors of workers from certain specific angles. For example, Li W et al. constructed a safety production behavior mechanism model based on the theory of planned behavior (TPB). Zhao et al. explored the impact of safety leadership on employee safety engagement. Ye et al. used self-exhaustion and self-efficacy as mediating variables to explore the relationship between safety stressors and construction workers' safety performance. Ji et al. considered multiple heterogeneities and studied the competition incentive mechanism of construction workers' safety behavior. Li Z et al. established an Agent model under the awareness of formal rules and herd mentality, and studied the unsafe behavior of construction workers. Ning et al. used an evolutionary game model to describe the decision-making interactions between the government and construction enterprises under the enterprise entity responsibility and third-party participation mechanisms.

Finally, some scholars have also made corresponding research on the prevention and control of workers' unsafe behaviors. For example, Peng and Zhang used an evolutionary game approach to provide managers with advice on how to handle the situation following a conflict among construction workers. Zhu et al. took the incentive and punishment mechanism into consideration and established an evolutionary game model to improve the effectiveness of construction safety management. Zijian et al. extracted recurring unsafe behavior scenarios in high-speed fall accidents through Bayesian network derivation based on a structurally constrained PC algorithm. Cong et al. developed a theoretical model for evaluating the communication performance of construction workers to enhance informal safety communication in the workplace.

To sum up, it can be seen that the research on unsafe behavior of workers shows a trend of diversification. Whether it is research content or research method, the research content mainly involves the formation mechanism and prevention strategies of the influencing factors of unsafe behavior, and the research methods mainly include Structural Equation Model, Evolutionary Game, Bayesian Network and Agent-Based Modeling.

This special issue is expected to provide valuable insights for building stakeholders to improve safety performance in practice, and at the same time, it guides future research in this research area.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Research on the Tournament Incentive Mechanism of the Safety Behavior for Construction Workers: Considering Multiple Heterogeneity

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The unsafe behavior of construction workers is one of the most important and direct causes of safety accidents. Managers usually develop effective incentives aimed at regulating worker safety behavior. Due to the large number of workers in construction projects, there are multiple differences in fairness preference, risk preference and ability level, which will lead to the complex effect of the traditional mechanism to regulate workers' safety behavior. In order to improve the effectiveness of incentive measures for worker safety behavior, this paper takes into account the multiple differences of individual workers' fairness preference, risk preference and ability level, based on the tournament mechanism to construct a competition incentive model. By designing a tournament reward and salary distribution for heterogeneous workers, the occurrence of unsafe behaviors can be reduced. The study found that in terms of the optimal level of safety investment, workers with risk aversion attitude generally invest higher than that of workers with risk preference, no matter whether they have a strong fairness preference or not; In terms of the distribution of tournament rewards, workers with a risk aversion attitude and a higher level of fairness preference need to be given higher incentives.

Keywords: construction workers, safety behavior, tournament incentive mechanism, multiple heterogeneity, risk appetite

INTRODUCTION

The engineering construction process usually faces the complex challenges of the construction environment, technology and on-site management, making it more prone to safety accidents than other industries (He et al., 2020). In China, in the first half of 2018, there were 1,732 safety accidents and 1,752 deaths in the construction industry, an increase of 7.8 and 1.4%, respectively (Han et al., 2019b). In the United States, there were more than 60,000 construction worker injuries in the construction industry in 2018, which was 32.6% higher than the average for all industries

(Han et al., 2019a). The construction industry has become one of the most dangerous industries, and the situation of construction safety is very severe. From the statistics on the frequency of fatal construction accidents published by the Occupational Safety and Health Administration (OSHA), the top five accidents (falling accident, electric shock accident, object strike, mechanical injury and collapse accident) are directly related to unsafe behavior of workers (Choe et al., 2016). Similarly, Oswald et al. (2018) proposed that 88% of accidents in construction projects involve unsafe behavior.

In order to effectively control and regulate the unsafe behavior of workers, managers and safety practitioners carry out a large number of interventions in the workplace, such as safety training, safety communication, safety rules and procedures, incentive measures, etc., aiming at improving workers' safety performance (Di Tecco et al., 2017; Wang et al., 2017; Kim et al., 2019). Among them, incentive measures are a proactive method commonly adopted by management. Financial incentives including money or prizes and non-financial incentives including evaluation feedback are all helpful to regulate workers' safety behaviors (Guo et al., 2018). However, for the construction team, the incentive problem in the construction phase is faced with more complex scenarios, and many factors such as external environment and institutional conditions, individual attributes, and dynamic interaction of multiple agents may affect the incentive effect. Among them, the existence of multiple heterogeneous attributes of workers has brought challenges to the formulation of incentive measures, which may make the incentive effect far from expectations.

First of all, the fairness preference heterogeneity of workers has a significant impact on the incentive effect of individuals. Fairness preference refers to workers' preference for fair income distribution, which is usually manifested in jealousy when workers' income is lower than others, resulting in negative utility. In fact, different agents have different fairness preferences. For example, some are selfish and jealous, and some emphasize fairness and reciprocity. A large number of scholars have studied the influence of fairness preference on incentive structure and incentive effect. For example, Grund and Sliwka (2005) found that fairness preference of employees will reduce the intensity of rewards and the incentive effect; Dubey et al. (2013) separately studied the influence of jealousy and pride on incentive structure and incentive effect; Gill and Stone (2015) discussed the interaction between fairness preference and self-worth in competition. Therefore, considering the heterogeneous characteristics of workers' fairness preferences is very necessary for the study of incentive mechanisms.

Secondly, the risk attitude of workers has a significant impact on the level of safety input (Kimbrough and Componation, 2009). Risk psychology has been studied by scholars for many years, but there is still not much practical guidance in the workplace. Because risk attitude has a significant impact on all factors of risk treatment, the impact of workers' risk attitude on construction safety should be fully considered during the project. Workers with different risk attitudes take different action choices when faced with possible risks or uncertain factors caused by information asymmetry. For a high-risk industry such as project construction, how to adjust incentive measures for workers with different risk attitudes is of great practical significance.

In addition, differences in the abilities of individuals will also affect the incentive effect on workers' safety behavior. Due to the different learning abilities of individual workers and the mastery of knowledge system in safe operation, the time and energy spent by each worker in safety investment will vary to a large extent (Gurtler and Krakel, 2010). For example, highly educated workers pay more attention to the importance of safety investment and work harder to learn safety regulations, reducing the occurrence of unsafe behaviors; experienced workers are more likely to avoid unsafe behaviors than workers with less work experience, etc. Therefore, in order to reduce the unfairness of asymmetric competition, we need to consider the formulation of incentives for workers of different ability.

As a new branch of the reward distribution system, the tournament mechanism is a very effective incentive method. The concept of tournament incentives originated from corporate governance and was first proposed by Lazear and Rosen (1981). It is actually a compensation plan for multiple agents. It is actually a compensation scheme for multiple entities, which is paid according to the ranking of individuals or teams in the organization. Higher performance means higher salaries for subjects with higher rankings. Among them, the salary gap between the higher-ranked and lower-ranked entities reflects the incentive intensity of the tournament mechanism (Zhang et al., 2017).

At present, scholars try to study the potential application of tournament incentive in various fields, such as sports competitions, the promotion of large-scale corporate executives the promotion of large-scale corporate executives and other issues. For example, a study by Kini and Williams (2012) found that tournament incentives would stimulate executives to work harder in corporate governance, thereby increasing their chances to the position of CEO. Altmann et al. (2012) analyzed the incentive effect of the multi-stage tournament incentive mechanism and found that wage differences can improve the work level of agents. Coles et al. (2018) found that the salary gap of tournament incentives is positively correlated with output performance and corporate risk. Huang et al. (2019) suggest that industry tournament incentives can increase the market revenue of products by motivating CEOs. The above-mentioned scholars have proved that tournament incentives have a positive effect on solving the problem of multi-agent incentives. Therefore, this paper takes the tournament as an incentive mechanism for workers' safety performance to study its influence on the unsafe behaviors in team work.

However, the current tournament mechanism must also consider some limitations and shortcomings. On the one hand, there is little literature on the impact of tournament incentives on construction project management, especially for the safety behavior performance of workers. On the other hand, the existing tournament incentive model only analyzes the impact of the pay gap on the input level of employees, and does not propose a specific salary distribution plan for heterogeneous workers. These limitations make it difficult to apply the tournament mechanism to the safety behavior incentives of construction workers in multiple heterogeneous situations. Therefore, in order to solve these problems, this research attempts to design a tournament reward distribution scheme based on the ranking of the safety performance and the degree of individual heterogeneity, to reduce unsafe behavior of workers and improve the safety performance of construction projects.

The main contributions of this article are: (1) Considering heterogeneity of the fairness preference, risk preference and abilities of the construction workers, making the motivated agents more realistic. (2) According to the characteristics of heterogeneity of construction workers, the tournament incentive mechanism was introduced into the incentive measures for workers' safety behavior, and incentive measures were improved. This research will find a new solution for the management and control of unsafe behaviors of workers with multiple heterogeneous characteristics, and provide a reference for formulating distribution plans for controlling the behavior.

BASIC HYPOTHESES

In order to comprehensively analyze the competition incentive model, according to the existing relevant literature and theoretical basis, we put forward the following hypotheses.

Hypothesis 1: Two construction workers in a team participated in the tournament. The work among construction workers is independent, and their work does not affect each other. This study does not consider the help and sabotage behavior among workers. At the same time, Construction workers pay attention to their incentive income and compare it with each other. Among them, e_i $(i = 1, 2)$ is the construction worker's safety investment level. Larger e_i means construction workers put more effort into safe construction.

Hypothesis 2: $c(e_i)$ represents the safety input cost of construction workers. Assuming that the input cost is a convex function, it indicates that when the safety input increases, the marginal cost of the safety input increases, that is $c(e_i)' > 0$, $c(e_i)'' > 0$. Therefore, the input cost of construction worker i is:

$$c(e_i) = ce_i^2 \tag{1}$$

In the formula, c is a constant.

Hypothesis 3: The safety performance score of construction workers π_i. When designing the safety performance salary distribution of the championship, the team needs to rank the safety performance evaluation scores of two construction workers. We set the safety output performance of each worker, that is, the safety performance assessment score is related to the safety input level of construction workers and the influence degree of uncertain factors (Griffin and Neal, 2000). It can be expressed as:

$$\pi_i = e_i + \varepsilon \tag{2}$$

where ε denotes a stochastic variable, which is subjected to a normal distribution. That is $\varepsilon \in (0, \sigma^2)$, representing external uncertainties. The probability that construction worker i ranks first is P_i, and $1 - P_i$ is the probability that construction worker i ranks second. According to the LR reward model (Grund and Sliwka, 2005), it can be expressed as:

$$P_i = prob(\pi_1 > \pi_2) = prob(e_1 + \varepsilon_1 > e_2 + \varepsilon_2)$$

$$= prob(\varepsilon_1 - \varepsilon_2 > e_2 - e_1) = G(e_2 - e_1) \tag{3}$$

Where $G(e_2 - e_1)$ and $g(e_2 - e_1)$ are respectively, the cumulative distribution function and density function of $c(e_i)$, Where $c(e_i)$ is the safety input cost function of construction workers. When the safety input level of workers is the same ($e_1 = e_2$), $G(e_2 - e_1) = G(0) = \frac{1}{2}$, $g(0) = \frac{1}{2\sigma\sqrt{\pi}} = \frac{1}{2\theta}$, where $\theta = \sigma\sqrt{\pi}$.

Hypothesis 4: The team manager distributes the incentive reward according to the ranking order of the safety performance evaluation scores. W_H is the income paid to the first-ranked worker, W_L is the income paid to the second-ranked worker, and ΔW is the payment difference.

Hypothesis 5: The output utility function of workers with heterogeneous ability. We use the worker's cost coefficient of safety input to describe the heterogeneity of worker abilities (Halisah et al., 2021; Niu et al., 2021). When $\alpha_i > 1$, it means that when the safety investment is the same, the worker i needs to pay more, that is, the ability of worker i is lower.

$$c(e_i) = c\alpha_i e_i^2 \tag{4}$$

Hypothesis 6: According to the previous analysis of fairness preference, during the implementation of incentives, construction workers will care about whether the results are fair (Mueller, 2020; Wu et al., 2020; Yan et al., 2020). In the model based on fairness preference, ∂ represents the pride preference of workers when they win rewards, and δ is the jealous preference when they lose, $0 < \partial < 1$, $0 < \delta < 1$. When ∂ and δ are equal to 0, it indicates that the construction worker has no fair preference.

Hypothesis 7: λ_i represents the risk attitude coefficient of worker i, $\lambda_i > 0$. When $0 < \lambda_i < 1$, it means that the risk attitude of worker i is preferred, so that the worker has a fluke and thinks that he can still get a better income without investing too much in safety behavior; When $\lambda_i = 1$, it means that the worker's risk attitude is neutral; When $\lambda_i > 1$, it means that the worker's attitude is to avoid risks. In addition, when the level of safety investment e_i is the same, the investment cost of employees $c(e_i)$ with risk preference is high. Then the relationship between the safety input cost of construction workers and after adding the risk heterogeneity is:

$$c(e_i) = \frac{c\alpha_i e_i^2}{\lambda_i} \tag{5}$$

Hypothesis 8: For workers, there is also a restriction on participation. Each worker has a retention effect. The reward given by the manager must ensure that the worker is willing to stay in his position and make safe investment. The expected utility of the position must be greater than or equal to the reserved utility of his own, otherwise, he is likely to find a way to change positions or switch jobs. Suppose that for construction worker ^{i}, his retention utility is U.

In this chapter, we combed the relevant literature and theories, put forward a series of assumptions as the basis, and paved the way for the later model construction.

TOURNAMENT INCENTIVE MODEL BASED ON HETEROGENEOUS CHARACTERISTICS

Model Establishment

(1) The expected utility of the worker (EU_i^H): According to Hypothesis 2, the net benefit of construction workers (U_i) is determined by the income paid by the manager (W_i), the effect of the fairness preference and the output of hard behavior $c(e_i)$. When construction workers rank first, workers will be proud of their victory. Therefore, the net benefit (U_i) increases the positive effect of fairness preference. At this time, the net benefit of construction workers is:

$$U_i^H = W_H + \partial \Delta W - c(e_i) \tag{6}$$

When the construction workers ranked second, the net benefit (U_i) reduced the negative effect of fairness preference. At this time, the net benefit of construction workers is:

$$U_i^L = W_L - \delta \Delta W - c(e_i) \tag{7}$$

Thus, the expected utility of the worker i is:

$$\begin{aligned} EU_i &= P_i U_i^H + (1 - P_i) U_i^L \\ &= P_i(1 + \partial + \delta)\Delta W + W_L - \delta \Delta W - c(e_i) \end{aligned} \tag{8}$$

(2) The manager's net benefit (EU_i):

According to Hypothesis 4, the safety output performance of construction workers is π_i, and the expenditure of managers is W_i. Since managers are risk-neutral, the expected net income of managers is:

$$EU = \pi_i - W_i = \pi_i - e_i - \varepsilon \tag{9}$$

(3) Competition incentive model: The incentive for construction workers is equivalent to solving the following problems:

$$\max EU = \pi_i - W_i = \pi_i - e_i - \varepsilon \tag{10}$$

$$EU_i^H = P_i(1 + \partial + \delta)\Delta W + W_L - \delta \Delta W - \frac{c\alpha_i e_i^2}{\lambda_i} \geq U \tag{11}$$

$$\max EU_i = P_i(1 + \partial + \delta)\Delta W + W_L - \delta \Delta W - \frac{c\alpha_i e_i^2}{\lambda_i} \tag{12}$$

According to the incentive model solution method, the optimal safety investment level of construction worker i is calculated:

$$e_i^* = \frac{h(e_i - e_j)(1 + \partial + \delta)\Delta W \lambda_i}{\alpha_i} \tag{13}$$

From the proof of Equation (13), we can know (1) The optimal safety input level e_i of construction workers is positively correlated with the pride preference ∂ of workers when they win the reward, jealousy preference δ of workers when they lose the reward, compensation gap ΔW and risk preference level λ_i, and negatively correlated with the cost coefficient of safety input α ; (2) In addition, e_i^* increases with the increase of incentive compensation gap ΔW. That is, the safety level of worker input has nothing to do with the absolute size of the bonus itself. That is, the safety level of worker input has nothing to do with the absolute size of the bonus itself. And it has to do with the difference between bonuses. The greater the difference, the higher the level of safety investment. Based on the principle of the tournament, the total amount is reduced, but the difference remains unchanged, and the desired incentive effect can also be achieved. Therefore, tournament incentives can achieve the expected incentive effect by paying different incentives to different workers according to their ranking in the tournament; (3) The optimal safety input level e_i^* decreases with the increase of safety input cost coefficient α_i. When α_i increases gradually, the difference between worker i and worker j increased. At this time, the safety input level of worker i will be significantly reduced, the winning probability of worker j will increase, thus the safety input level of worker j will also decrease, and the probability of accidents caused by unsafe behavior will greatly increase. Therefore, for team managers, how to allocate personnel and resources, arrange workers with the same ability as much as possible in an evaluation system, or conduct more relevant training for low-ability workers to improve their ability to the same level. It is to increase the enthusiasm of workers to invest in safety and effectively reduce the unsafe behaviors of workers.

Design of Incentive Coefficient Based on Multiple Heterogeneity

The purpose of designing competition incentives for heterogeneous workers in construction projects is to achieve the allocation of completion goals of project and reward resources. The above analysis proves that establishing an incentive mechanism based on their ranking for heterogeneous abilities can help workers propose the optimal level of safety investment. In order to quantify the ideal tournament incentive effect, this section will calculate and discuss the incentive coefficients in the tournament incentive model. Construction projects often use linear incentive contracts to motivate participants (Fang et al., 2016). According to the HM linear incentive model, it is assumed that the principal has all the output. In order to motivate the agent, the principal must pay remuneration to the agent. And part of the reward is linked to some objective evaluation indicators (such as profit, output and product quality), then:

$$W_i = b+\beta\pi_i \tag{14}$$

Among them, b is the fixed income paid by the owner to the construction workers; in addition, β_i is the incentive coefficient, $\beta_i \in (0, 1)$. In particular, β_1 is the incentive coefficient of the construction worker ranked first in the competition; $\beta_2 = q\beta_1$ is the incentive coefficient of the second place. q is the decreasing incentive coefficient, $0 < q < 1, 0 < \beta_2 < \beta_1$.

(1) Net income of construction workers (w_i): Under the incentive of the tournament, the actual net income of top-ranked worker is positively correlated with W_i, positive effect of fairness preference ($\partial \Delta W$), and negatively correlated with safety input costs $c(e_i)$.Therefore, the net income of the construction workers ranked first can be expressed as:

$$\begin{aligned} w_i &= W_i - c(e_i) + \partial(W_i - W_j) \\ &= b+\beta_1\pi_i - \tfrac{c\alpha_i e_i^2}{\lambda_i} + \partial\left[b+\beta_1\pi_i - (b+\beta_2\pi_j)\right] \\ &= b+\beta_1(e_i+\varepsilon_i) - \tfrac{c\alpha_i e_i^2}{\lambda_i} + \partial\left[\beta_1(e_i+\varepsilon_i) - \beta_2(e_j+\varepsilon_j)\right] \\ &= b+\beta_1 e_i - \tfrac{c\alpha_i e_i^2}{\lambda_i} - (\partial\beta_1 e_i - \beta_2 e_j) + \beta_1\eta \end{aligned} \tag{15}$$

Among them, $\eta = \varepsilon_i + \partial(\varepsilon_i - q\varepsilon_j)$, η is a random variable that obeys a normal distribution. It represents the overall interference from the outside world. Since two construction workers are working on the project together, it is believed that the external interference received by the two workers is similar, thus $\varepsilon \in (0, \sigma^2)$.

The actual net income of the construction workers ranked second (w_j) is positively correlated with the incentive benefits of the manager (W_j), and negatively correlated with the safety input cost of productive efforts $c(e_i)$ and the reverse effect of fairness preferences ($\delta \Delta W$).Then, the net income of construction workers ranked second can be expressed as:

$$\begin{aligned} w_j &= W_j - c(e_j) - \delta(W_i - W_j) \\ &= b+\beta_2\pi_j - \tfrac{c\alpha_j e_j^2}{\lambda_j} + \delta\left[b+\beta_1\pi_i - (b+\beta_2\pi_j)\right] \\ &= b+\beta_2(e_j+\varepsilon_j) - c\alpha_j e_j^2 + \partial\left[\beta_1(e_i+\varepsilon_i) - \beta_2(e_j+\varepsilon_j)\right] \\ &= b+\beta_2 e_j - \tfrac{c\alpha_j e_j^2}{\lambda_j} - \partial(\beta_1 e_i - \beta_2 e_j) + \beta_2\mu \end{aligned} \tag{16}$$

Among them, $\mu = \varepsilon_i - \delta(\varepsilon_i/q - \varepsilon_j)$ represents the overall interference from the outside world. Therefore, μ is a random variable that obeys a normal distribution, thus $\varepsilon \in (0, \sigma^2)$.

According to transaction cost economics (Liu et al., 2016), the deterministic equivalent income of the top-ranked worker ($\widetilde{w}_i$):

$$\begin{aligned} \widetilde{w}_i &= w_i - \tfrac{1}{2}\rho Var(w_i) = w_i - \tfrac{1}{2}\rho(w_i - Ew_i)^2 \\ &= b+\beta_1 e_i - \tfrac{c\alpha_i e_i^2}{\lambda_i} + \partial(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_1^2\sigma^2}{2} \end{aligned} \tag{17}$$

Similarly, the deterministic equivalent net income of second-ranked worker j is:

$$\begin{aligned} \widetilde{w}_j &= w_j - \tfrac{1}{2}\rho Var(w_j) = w_j - \tfrac{1}{2}\rho(w_j - Ew_j)^2 \\ &= b+\beta_2 e_j - \tfrac{c\alpha_j e_j^2}{\lambda_j} - \delta(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_2^2\sigma^2}{2} \end{aligned} \tag{18}$$

(2) The net total benefits to the manager: According to Hypothesis 4, managers are risk-neutral (Liu et al., 2016). Therefore, the expected net income of managers is:

$$\begin{aligned} EU &= \pi_i - W_i + \pi_j - W_j \\ &= \pi_i - (b+\beta_1\pi_i) + \pi_j - (b+\beta_2\pi_j) \\ &= (1-\beta_1)\pi_i - b + (1-\beta_2)\pi_j - b \end{aligned} \tag{19}$$

(3) Incentive model: Based on the classic HM principal-agent incentive model, the following constraint planning problems need to be solved when designing the tournament incentive mechanism.

For construction worker i, need to meet:

$$\begin{aligned} &\max(1-\beta_1)\pi_i - b \qquad (PC) \\ &b+\beta_1 e_i - \tfrac{c\alpha_i e_i^2}{\lambda_i} + \partial(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_1^2\sigma^2}{2} \geq w_0 (IR) \\ &\max b+\beta_1 e_i - \tfrac{c\alpha_i e_i^2}{\lambda_i} + \partial(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_1^2\sigma^2}{2} (IC) \end{aligned} \tag{20}$$

For construction worker j, need to meet:

$$\begin{aligned} &\max(1-\beta_2)\pi_j - b \quad (PC) \\ &b+\beta_2 e_j - \tfrac{c\alpha_j e_j^2}{\lambda_j} - \delta(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_2^2\sigma^2}{2} \geq w_0 (IR) \\ &\max b+\beta_2 e_j - \tfrac{c\alpha_j e_j^2}{\lambda_j} - \delta(\beta_1 e_i - \beta_2 e_j) - \tfrac{\rho\beta_2^2\sigma^2}{2} (IC) \\ &\beta_2 = q\beta_1 \end{aligned} \tag{21}$$

According to the solution method of incentive model, the optimal safety input level and incentive coefficient of the first and second construction workers are, respectively:

$$e_i = \frac{\beta_1\lambda_i(1+\partial)}{\alpha_i} \tag{22}$$

$$e_j = \frac{\beta_2\lambda_j(1+\delta)}{\alpha_j} \tag{23}$$

$$\beta_1 = \frac{\lambda_i(1+\partial)}{1-\partial^2+\alpha_i\sigma^2} \tag{24}$$

$$\beta_2 = \frac{\lambda_j(1+\delta)}{1-\delta^2+\alpha_j\lambda_j\sigma^2} \tag{25}$$

According to Equations (24) and (25), we obtain the incentive coefficients of the first (β_1) and second-ranked construction worker (β_2). In order to facilitate the analysis, this section selects two workers to establish the model. It is worth noting that this incentive model is also applicable to tournament involving multiple construction workers ($i > 2$). According to the above

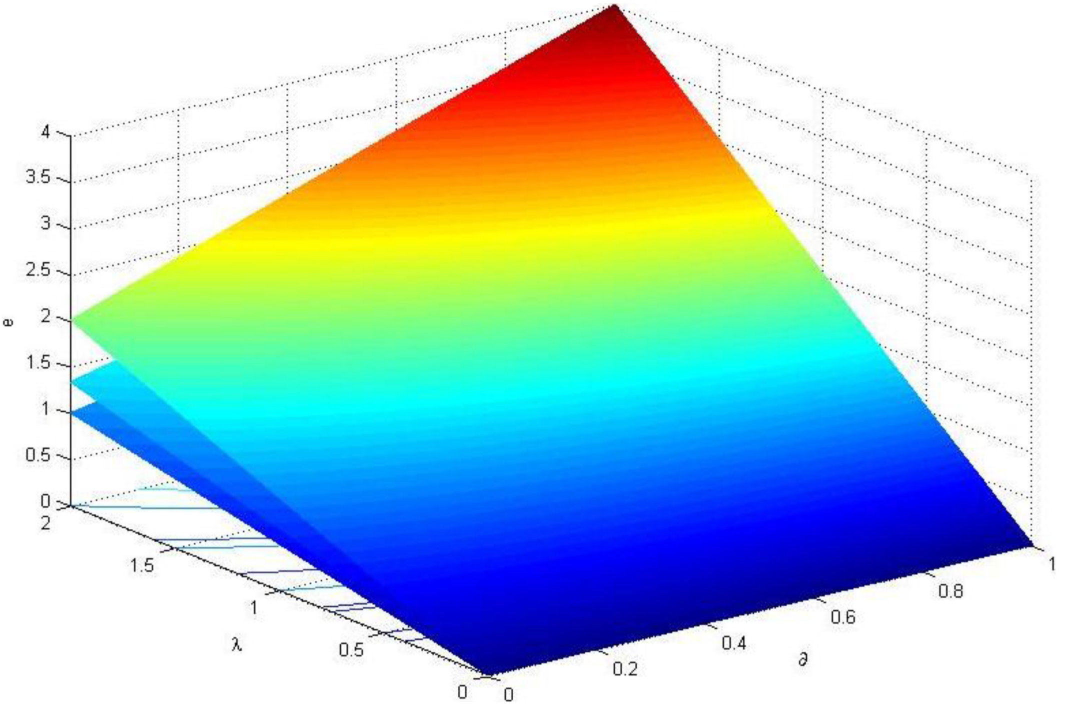

FIGURE 1 | The trend of the optimal safety input level e_i * of construction workers (σ^2=0.8).

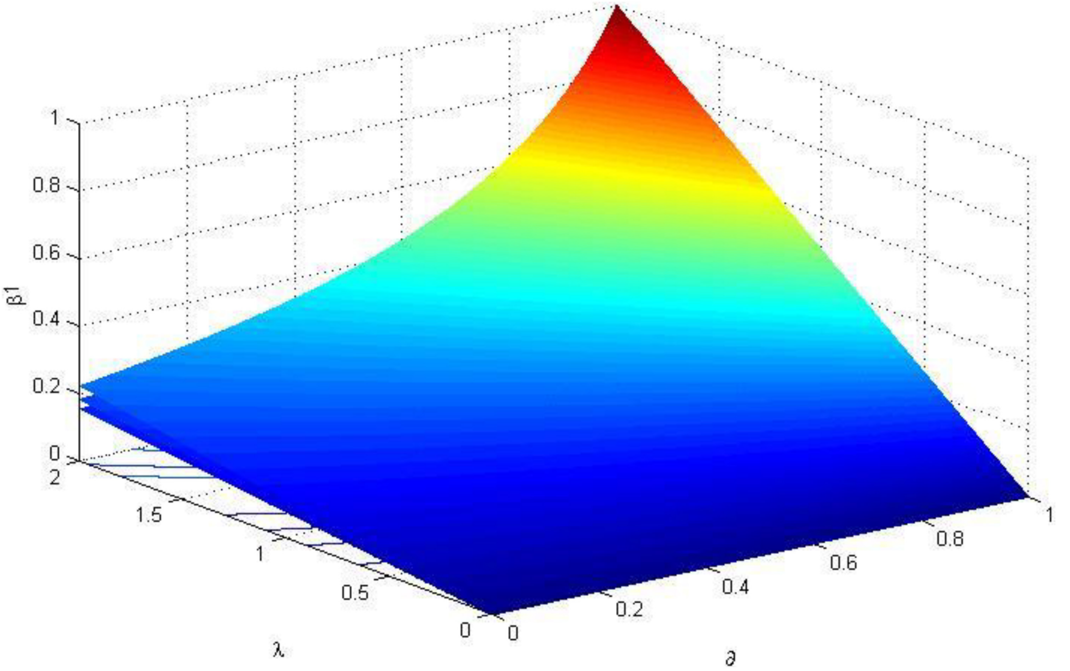

FIGURE 2 | The trend of the incentive coefficient of the first-ranked worker β_1 (σ^2=0.8).

calculation, when there are more than two workers participating in the competition, the incentive coefficient of the third-ranked is $\beta_3 = q\beta_2 = q^2\beta_1$. Therefore, the incentive coefficient of the nth-ranked worker is $\beta_n = q^{n-1}\beta_1$.

Analysis Results

According to the results of the championship incentive model, the following analysis results:

(1) The results of salary incentives Equations (13) show that the optimal safety input level (e_i^*)is positively correlated with the salary gap (ΔW). The optimal safety investment level (e_i^*) increases with the increase of ΔW given by the manager. Conversely, according to ΔW=$\beta_1\pi_1 - \beta_2\pi_2 = \beta_1(e_1 - qe_2)$, it can be seen that the greater the safety input gap, the greater the ΔW. This forms a virtuous incentive cycle, and the salary incentive mechanism is an effective means to improve workers' optimal effort. The team manager can keep the reward gap unchanged and retain the utility to minimize the total reward. That is, workers will not increase unsafe behaviors due to relaxation in this situation.

(2) According to the Equations (22) and (23), the optimal safety input e_i^* of the first and second-ranked construction workers is inversely proportional to their cost coefficient of safety input (α_i) and risk preference λ_i. In addition, the optimal safety input (e_i^*) of the first-ranked worker is proportional to the reward preference coefficient when winning the first place, and the optimal safety input j of the second-ranked worker is proportional to the jealous preference coefficient when losing the first place. This indicates that the optimal safety input (e_i^*) is positively correlated with the fair preference coefficients ∂ and δ. Compared with the competition incentive model without considering the fair preference, the workers' optimal effort level is improved with the consideration of the fair preference. Regardless of the rank of the workers, the optimal safety input of workers always increases with the increase of the fairness coefficient.

(3) Combining Equations (12), (22), and (23), we can study the impact of championships on workers' unsafe behaviors under the situation of heterogeneous ability. When the worker's cost coefficient of safety input α_i gradually increases, the degree of heterogeneity of the ability of the two workers increases, and the worker's optimal safety input will also decrease significantly. Due to the lack of effort of the workers, the probability of accidents has greatly increased, and the championship mechanism has become inefficient. At the same time, as the degree of heterogeneity of the two workers' abilities increases, the winning probability of worker i gradually increases, and the winning probability of worker j gradually decreases. In a practical sense, when scoring safety performance, the score of i is more likely to be ahead of the score of j. This is likely to cause the dissatisfaction of $j$and lead to a negative attitude. Therefore, for team managers, how to deploy personnel, arrange workers with the same ability as much as possible in an evaluation system, or conduct more relevant training for low-ability workers to improve to high level. It is a prerequisite for increasing the enthusiasm of workers to invest in safety behaviors and enabling the tournament mechanism effective.

(4) According to the calculation results of the incentive coefficients β_1 and β_2 in Equations (23) and (24), it can be

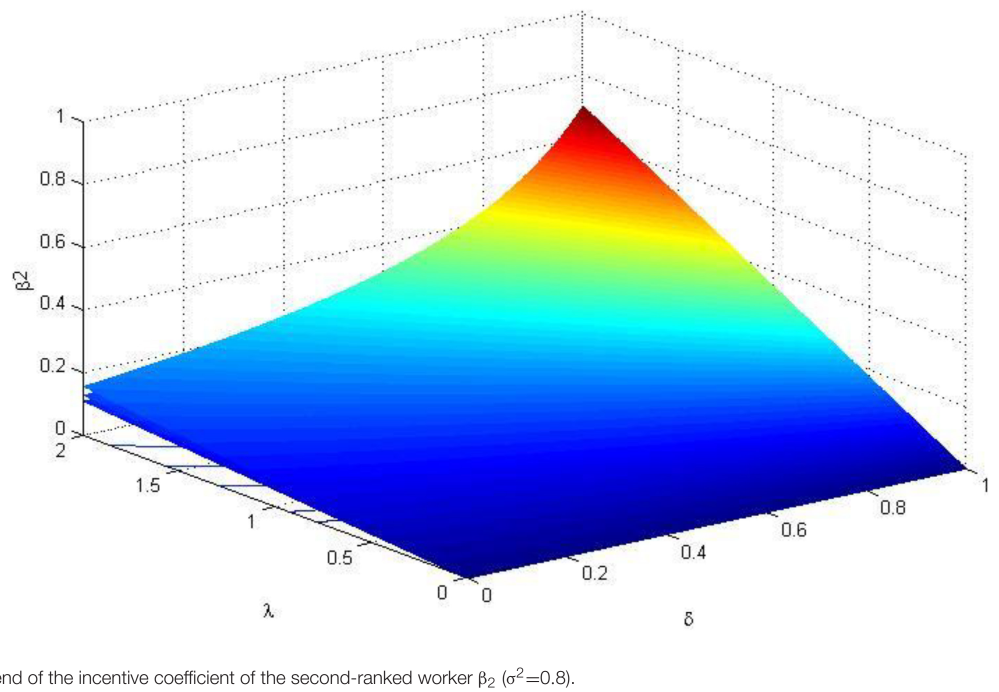

FIGURE 3 | The trend of the incentive coefficient of the second-ranked worker β_2 (σ^2=0.8).

calculated that the partial derivative of the fair preference coefficient ∂ to the incentive coefficient β_1 is greater than 0. Similarly, the partial derivative of the incentive coefficient (β_2) is also greater than 0. That is, the two incentive coefficients are both incremental functions of the fairness preference coefficient. Therefore, the higher the level of fairness preference, the greater the value of incentive coefficients β_1 and β_2. In addition, as the safety performance ($\pi_i = e_i + \varepsilon$) of construction workers increases with e_i and e_j, therefore, increasing the incentive coefficient can indirectly lead to an increase in the overall safety performance of the construction project.

NUMERICAL ANALYSIS

In the pre-construction stage, the manager should determine the competition incentive clauses based on the fairness preference (∂ and δ), the risk preference coefficient λ_i of each construction worker, and the influence of uncertain factors σ^2. It is worth noting that the working abilities of these two construction workers are different, and the safety input cost coefficient of each construction worker is α_i. Team managers can obtain the fairness preference (∂ and δ), and risk preference λ_i ($\lambda_i \in (0, 1)$) of each worker through questionnaires. By judging the complexity of technology and the external natural environment, the value of uncertain factors $\sigma^2 \in (0, 1)$ can be determined.

In order to formulate a reasonable incentive coefficient, the relationship between the fair preference coefficient, risk preference coefficient, safety input cost coefficient, the first and second ranked incentive coefficient are analyzed in this section. Using MATLAB to visualize the analysis results, the relationship between the parameters is shown in **Figures 1–3**.

In the three-dimensional coordinate system of **Figure 1**, the three curved surfaces from top to bottom are the levels of optimal safety investment when the cost coefficient of safety investment α_i=1, α_i= 1.5, α_i= 2. It can be seen from the figure that when α_i increases, the optimal safety investment e_i^* also increases. And the higher the worker's ability, the greater the slope of the surface corresponding to the ability, that is, the marginal effect of α_i increases. When α_i is fixed, the optimal level of safety investment e_i^* is positively correlated with the pride ∂ when winning the reward or the jealousy δ when losing the reward in the fairness preference. When $0 < \lambda_i < 1$, that is, when the worker's attitude is risk preference, the worker's safety input level e_i^* is generally low, and the safety input level does not change much with the increase of fairness preference; When $\lambda_i > 1$, the worker's risk attitude is evasive, and the safety input level e_i^* increases rapidly as the degree of fairness preference ∂ and λ_i strengthen. This finding shows that, regardless of whether the fairness preference is strong or not, workers with risk-averse attitudes generally have lower safety investment than workers with risk preference.

It can be seen from **Figures 2**, **3** that the incentive coefficient trends of the first-ranked worker *i* and the second-ranked worker *j* are consistent. In the three-dimensional coordinate system of **Figures 2**, **3**, the three curved surfaces from top to bottom are the incentive coefficients when the safety input cost coefficient α_i=1, α_i= 1.5, α_i= 2. In the case of α_i unchanged, when the first worker's pride preference c increases, the incentive coefficient β_1 increases. Since the excitation coefficient of the second place is $\beta_2 = q\beta_1$, $(0 < q < 1)$, the excitation coefficient β_2 also increases accordingly. When the safety input cost coefficient α_i decreases (that is, the capability of safety increases), the incentive coefficients β_1 and β_2 increase; When the values of ∂ and λ_i are low, the excitation coefficient increases slowly with the increase of ∂ and λ_i; When $\partial > 0.6$ and $\lambda > 1$, that is, only when the level of fairness preference is high and the risk attitude is evasive, the incentive coefficient increases rapidly. Therefore, managers should give higher incentive coefficients to workers who risk aversion and a high level of fairness preference.

DISCUSSION AND CONCLUSION

Discussion

The tournament incentive model designed in this paper fully considers the role of competition and the heterogeneous characteristics of multiple participating workers. It can be seen from the analysis results of the model that the tournament considering fairness preference can motivate workers to increase their safety investment. And verify the conclusions of this paper through the analysis of examples.

Tournament incentives based on the heterogeneous characteristics of workers can play the following two roles: (1) The salary gap in tournament can motivate all workers to increase safety investment during the construction process; (2) For construction workers with a higher level of fairness preference and risk aversion, the manager should formulate a larger incentive coefficient. This cannot only optimize the safety investment of each worker, but also provide more benefits for managers, thus creating a win-win situation.

When implementing the tournament incentive mechanism, it should be noted that: (1) Workers' risk aversion attitude has a more obvious impact on their safety investment than fairness preference. When workers' risk-averse attitudes are evasive, the remuneration given by managers can get more workers' safety input in return. Therefore, shift managers should avoid to choose workers with a risk attitude of preference. When they have to adopt workers with a risk attitude preference, the manager should try to arrange workers with similar preferences to compete in a team. (2) In multiple rounds of repeat tournaments, workers can roughly figure out the ability level of their opponents through the previous rounds. Employees with high ability may reduce their efforts, while employees with low ability may also think that they have the low probability of winning it and gave up. As a result, tournaments can lead to inefficiency.

Conclusion

Unsafe behavior is the most important and direct cause of accidents. Managers usually develop effective incentives to improve the safety performance of employees. Due to the large number of workers in construction projects, and these workers usually have uneven abilities and differences in various qualities, the time and energy spent by each worker in safety investment will vary to a large extent. Managers need to achieve effective and safe work incentives for heterogeneous workers through salary rewards, thereby reducing the occurrence of unsafe behaviors. By introducing the novel reward means of competition mechanism, this paper considers many psychological factors such as construction workers' fairness preference, risk preference and ability difference, constructs the competition incentive mechanism model from the perspective of workers' heterogeneity, and introduces it into workers' safety behavior incentive measures. In this way, this study provides a new scheme to control the unsafe behavior of heterogeneous workers, and also gets a series of management enlightenment:

(1) Managers should pay attention to the differences in the fairness preference, risk preference and ability of construction workers, and try to choose workers with lower risk preference. The research has found that workers with risk-averse attitudes generally have a higher level of safety investment regardless of whether they have a strong preference for fairness.
(2) Managers can stimulate workers' fairness preferences. After selecting a construction worker group, this can be achieved by designing reasonable competition contract clauses. Moreover, the reward gap is an effective way to encourage workers to invest their best efforts. On the premise of satisfying the incentive compatibility constraints of the model, managers can appropriately increase the incentive gap to achieve the best level of safety input.
(3) The different risk attitudes have the most significant impact on the safety investment level of miners participating in the tournament mechanism. The derivation of the model shows that workers whose risk attitude is evasive can bring a higher level of safety input, while workers whose risk attitude is preferred are significantly lower in safety input. The greater the difference in risk attitudes among workers, the more inefficient the incentive mechanism will be.
(4) As the degree of heterogeneity among workers increases, unsafe behaviors of workers generally increase. Therefore, for team managers, personnel and resource allocation are required. Try to arrange workers with the same ability and the same preference in one evaluation system, or provide more relevant training for workers to improve their ability to the same level. This is a prerequisite for improving workers' safety input enthusiasm, effectively reducing the occurrence of unsafe behaviors of workers.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

LJ, YZ, and WL: conceptualization. WL and YZ: methodology. LJ: software, supervision, investigation, project administration, and funding acquisition. LJ and WL: validation. WL: formal analysis, resources, data curation, writing—original draft preparation, and visualization. LJ and YZ: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Research on Unsafe Behavior of Construction Workers Under the Bidirectional Effect of Formal Rule Awareness and Conformity Mentality

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At present, China's engineering safety management has developed to a certain level, but the number of casualties caused by construction accidents is still increasing in recent years, and the safety problems in the construction industry are still worrying. For purpose of effectively reducing construction workers' unsafe behavior and improve the efficiency of construction safety management, based on multi-agent modeling, this paper analyzes the influencing factors during construction workers' cognitive process from the perspective of safety cognition, constructs the interaction and cognition of the agent under the bidirectional effect of formal rule awareness and conformity mentality model, and set behavior rules and parameters through the Net Logo platform for simulation. The results show that: Unsafe behavior of construction workers is related to the failure of cognitive process, and the role of workers' psychology and consciousness will affect the cognitive process; The higher the level of conformity intention of construction workers, the easier it is to increase the unsafe behavior of the group; Formal rule awareness can play a greater role only when the management standard is at a high level, and can correct the workers' safety cognition and effectively correct the workers' unsafe behavior; Under certain construction site environmental risks, the interaction between formal rule awareness and conformity mentality in an appropriate range is conducive to the realization of construction project life cycle management. This study has certain theoretical and practical significance for in-depth understanding of safety cognition and reducing unsafe behavior of construction team.

Keywords: formal rule awareness, conformity mentality, safety cognition, unsafe behavior, multi-agent modeling

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INTRODUCTION

The construction industry plays an important role in promoting the development of the national economy (Zhou et al., 2015). According to the 2020 National Economic and Social Development Statistical Bulletin of the National Bureau of Statistics (China Statistics, 2021), the total added value of the construction industry throughout the year was 7,299.6 billion yuan, an increase of 3.5% over the previous year. However, the safety production situation in the construction industry is still very serious. According to a report from the Ministry of Housing and Urban-Rural Development of the People's Republic of China (Standardization of Engineering Construction, 2020), in 2019, a total of 773 housing engineering safety accidents occurred nationwide, and 904 people died, a year-on-year increase of 5.31 and 7.62%. It is worth pondering that at present, China's engineering safety management has developed to a certain level. The attitude of engineering managers toward safety issues, the rules and regulations of safety management, the application of equipment and technology, and the safety atmosphere and awareness of construction subjects are all showing a good development trend. However, why are engineering safety accidents still emerging one after another?

Research evidence has shown that human unsafe behavior is the most important reason affecting construction safety production (Park et al., 2020; Zhang et al., 2020). Among the accidents on construction sites, 90% are caused by human errors (Newaz et al., 2020), and 88% of construction engineering accidents involve human unsafe behavior (Suraji et al., 2001). An effective strategy to enhance the safety production management and the safety production performance of construction projects is to prevent and control unsafe behaviors of workers (Fang et al., 2019; Jiang et al., 2020).

Workers' unsafe behavior is a manifestation of cognitive failure. Workers' safety cognition belongs to the category of psychological research on worker behavior (Wang et al., 2016), which has become one of the most concerned issues in construction site safety research (Liao et al., 2017). Recently, domestic and foreign scholars have carried out a large number of studies on cognitive process (Cheng, 2020), cognitive failure (Cheng, 2020) and cognitive factors (Goh and Sa'Adon, 2015), and analyzed factors such as safety awareness (Fang and Cho, 2016), safety attitude (Han et al., 2019) and behavior control (Hamilton et al., 2019). The impact of this has made an important contribution to clarifying the causal relationship of safety cognition. However, the research on unsafe behaviors from the perspective of construction workers' individual cognition is still insufficient, ignoring the role of construction workers' psychological and consciousness changes in the interaction process. Safety cognition is a process of continuous dynamic change, which will be affected by various changing factors, such as workers' psychological activities and environmental factors. As the most basic and core component of the construction team, construction workers, the interaction of individuals in the group will directly affect the workers' own safety cognition (Peiró et al., 2020). Conformity mentality and formal rule awareness lead to unsafe behavior through the interaction of construction workers, which is a major problem in team management (Ahn et al., 2013; Aljadeff et al., 2020). Conformity is defined as Individual behavior is affected by the behavior of team members, judged and cognized according to the internal norms of the team, which will force individual behavior to be consistent with group behavior and finally manifested as gregariousness (Wang and Chen, 2021), and affects the agents' cognitive differences and risk steady-state cycle (Liu and Ding, 2021). Workers' formal rule awareness determines the weight of formal standards relative to perceived standards (Ahn et al., 2013). When an individual forms an internal standard and there is a difference between the internal standard and the formal standard, the workers' awareness of formal rules often adjusts themselves to reduce the difference to accept the behavior (Carver and Scheier, 1982). It determines the degree of workers' recognition of the rules and regulations formulated by the management, and affects workers' learning, recognition and compliance with management norms. It is an important research content of safety production management. Construction workers have been engaged in production and life in teams and groups for a long time. The mutual influence and interaction between agent and the environment and between agents have provided impetus for system evolution (Zhang et al., 2003). On the one hand, formal rule awareness and the conformity mentality affect the binding force of management norms. On the other hand, the colleague effect establishes the behavioral connection between individuals and colleagues and influences each other. As a result, workers will not only adjust their own decisions based on colleagues' behavioral decisions, but may also have different perceptions of production tasks and risk identification. Considering the two-way effect of conformity mentality and formal rule awareness can clarify the decision-making basis and cognitive differences of unsafe behaviors of construction workers, ensure that management norms play a restrictive role and achieve the objectives of safe production management.

Although more and more scholars begin to pay attention to the role of construction workers' cognition and psychology, how to use workers' individual safety cognition to reduce the unsafe behavior of construction team and obtain management enlightenment can be further studied. Therefore, based on the analysis of the influencing factors of workers' safety cognition, this study explores the relationship between safety cognition and unsafe behavior, establishes the relationship between workers' conformity effect and rule consciousness and workers' cognitive process, and verifies the importance of correct workers' cognitive process; Analyze the role of formal rule awareness and conformity mentality in group unsafe behavior and the improvement effect on individual and group behavior from the cognitive process of workers, in order to obtain effective management strategies and prevent unsafe behavior of construction team. This study innovatively considers the influence of the two dimensions of rule awareness and conformity mentality, and studies the effect of them on the unsafe behavior of construction teams under different situation combination; On the other hand, it combines workers' safety cognitive process with risk perception to study workers' behavior decision-making, so as to enrich the research on construction workers' cognitive psychology. At the same time, using computational experiments to simulate, to a certain extent, promote the process of combining psychological theory with computational simulation methods to study practical problems.

In order to study the above problems, this article uses multi-agent modeling (ABM) to simulate the evolution of construction workers' unsafe behavior decisions. Construction workers are a group of complex and diverse agents, whose heterogeneity leads to the diversity of behavioral decisions. In view of the advantage that ABM can simulate the interaction between complex, non-linear and discrete subjects, it is convenient to observe the group effect produced by individuals from bottom to top (Li et al., 2021). Therefore, multi-agent modeling is the most appropriate. Considering the advantages and disadvantages of each simulation platform, in order to fully describe the characteristics of the agent and environment, combined with the applicable scenarios of relevant software, this paper selects the Net logo platform to simulate and analyze the unsafe behavior of construction workers. In the second part, this paper first combs the general model of construction workers' interaction and safety cognition, and explains the process and main variables of safety cognition combined with the actual environment of construction workers. Then, we summarize the relationship among some influencing factors of construction workers' cognitive process, establishes the behavioral rules of workers' social cognitive mechanism of unsafe behavior, and initializes the model. Finally, the third part carries out experimental simulation to study their two-way effect by the combination of formal rule awareness and conformity mentality.

MODEL DEVELOPMENT

Agent Interaction Setting

Based on the question of what is the cognitive process construction workers who adopt dangerous behavior and using multi-agent modeling, this paper aims to study the occurrence mechanism of workers' unsafe behavior under the two -way action of formal rule awareness and conformity mentality. The environment of the construction site is complex. Due to different management levels and technical complexity, there will be great differences in environmental risks. At present, there is no unified classification standard for the classification of environmental risk on the construction site, but various studies show that the environmental risk on the construction site will affect the unsafe behavior of workers. This model introduces site risk (*SA*) to describe the degree of unsafe construction site. For example, the site risk is 15%, which means that the worker has a 15% probability of being in a dangerous environment. At the same time, workers will get an actual site risk *AR*(actual risk), the actual site risk is defined to obey the Normal distribution$N\left(\mu, \sigma^{2}\right)$.

In this paper, the interactive behavior of agents is mainly reflected in the learning and imitation behavior among workers. There is an interactive relationship between workers' behavior and decision-making, and they often deviate from their original choice and make decisions in line with group behavior preferences (Yang et al., 2009). The learning and imitating behaviors of workers in team work is a major way to replicate unsafe behaviors. Research has found that if someone in the construction group takes unsafe behavior, it is likely to trigger herd behavior (He et al., 2020). Workers' behavior is usually affected in two ways. One comes from the colleague effect, that is, the influence of the behavior of surrounding workers. When making decisions, workers will refer to the actions taken by their colleagues; the other comes from the formal rules set by the management, which can restrict workers' unsafe behaviors. The interaction between workers, colleagues and management is shown in **Figure 1**. The colleague effect and the formal rules of management mainly affect the second and third stages of workers' safety cognition. The production and life circle of construction workers are mainly concentrated within the team, and the interaction between workers is significant. The personal sense of security mainly depends on the safe words and deeds of team members, accident occurrence, etc, (Han et al., 2015). In the construction environment, the most direct impact that workers receive comes from their colleagues. Research shows that co-workers' behavior is the main factor affecting safety cognition (Qiu and Yu, 2019). When workers perceive risks in the second stage, they are not only derived from their own perception of risks, but also affected by the acceptance of risks by surrounding workers. As a decision maker, the ability of managers and the management decisions they make will have a significant effect on workers' perception and decision-making and safety performance (Cao et al., 2011). Workers in construction team must consider the formal rules set by the management when they perceive the reaction to form a risk acceptance.

Behavior is the product of cognition (Zhang and Fang, 2012), so cognition has an important influence on the occurrence and evolution of behavior. Workers may have correct perceptions of the real environment, or they may have distorted perceptions and make wrong decisions. In this process, people obtain information, process information, and finally reflect it in the agent's behavior. Based on the cognitive process proposed by Fang Dongping and the actual environment of construction workers, this article explains the safety cognitive process and main variables as follows. The cognitive process of workers will go through the following five stages:

(1) Discovery of hazard information. It refers to whether workers can find the source of hazards at the construction site, and whether they can find hazards is the first step to avoid unsafe behavior. Whether workers can discover on-site risks depends on the workers' safety awareness (*SA*) and safety knowledge (*SK*). The higher the safety awareness and the richer the safety knowledge the workers have, the easier it is to identify the field risks.
(2) Understand hazard information. After workers discover the risks on site, they evaluate the risks.
(3) Perceived response. Workers retrieve their own long-term memory, and at the same time, they will be affected by factors such as the external environment to form a risk acceptance (*RA*).
(4) Select response. At this stage, workers will decide which response mode to take from the possible responses.
(5) Take action. This refers to whether workers can implement their own decisions. For example, when workers decide to take safety actions, they need to control themselves, make no mistakes, avoid sudden accidents, and fully implement their decisions.

Workers will be affected by multi-dimensional factors when they are in the process of safety cognition, including individual factors and environmental factors (Ye et al., 2020). Individual factors refer to factors such as workers' own safety awareness, safety knowledge and other factors that affect their cognitive level. Factors such as behavior feedback, demonstration effects, and safety training will affect workers' individual factors. We define them as external environmental factors. We combed the relationship between some influencing factors of workers'

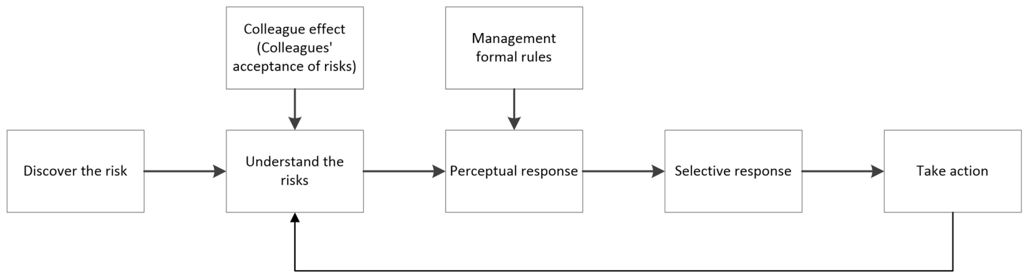

FIGURE 1 | Worker interaction diagram.

cognitive process, as summarized in **Figure 2**. Among them, the three parameters of environmental risk level, conformity mentality and formal rule awareness actually represent what kind of risk environment workers are in, how fast workers evaluate workers' behavior and regard it as their own code of conduct, and the gap between formal rules and workers' internal standards. The conformity mentality can be understood as the dependence of construction workers on workers' behavior. Workers form subjective norms through learning and imitating the behavior of co-workers. Whether workers prefer their own judgment or colleagues' behavior still has supplementary research space on the impact of this on unsafe behavior. The formal rule awareness of construction workers affects the acceptance of management norms. Management can improve workers' formal rule awareness through safety training and safety education, which will have an impact on individual factors such as construction workers' safety attitude, and then affect workers' safety cognition process.

Agent Behavior Rules Setting

Based on the cognitive process and risk perception that affect the unsafe behavior of construction workers, we established the behavioral rules of the social cognitive mechanism of unsafe behaviors of workers. **Figure 3** summarizes the main rules of the agent's actions. When a worker is in a construction site with a certain risk, the worker first judges whether the site risk can be found, and then perceives the risk information. Their own safety attitude, colleague effect, and management norms will affect the worker's risk acceptance. Workers judge whether they accept the risk according to their personal risk acceptance, and finally take safe or unsafe actions.

(1) Discovery of hazard information stage

When construction workers enter the working environment, whether they can find dangerous mainly depends on the workers' safety knowledge and safety awareness. With less safety knowledge, workers cannot recognize hazards; with lower safety awareness, workers will not pay attention to the dangers around them. Whether workers can find danger at time t (FR_i^t) is calculated by formula (1).

$$FR_i^t = \begin{cases} 0, rand(0,1) \geq SA_i^t \times SK_i^t \\ 1, rand(0,1) < SA_i^t \times SK_i^t \end{cases} \quad (1)$$

SA_i^t is safety awareness of worker i at time$t$, SK_i^t is safety knowledge of worker i at time$t$, $FR_i^t = 0$ represents that the worker i did not detect and discover the risk or danger at time$t$, FR_i^t = 1 represents the worker i discovered dangerous information at time l.

(2) Perceived risk stage

If workers find a danger, they will then perceive the risk. Risk perception is workers' own subjective perception and assessment of the dangerous environment they are in Choi and Lee (2018). Therefore, even in the same site risk environment, the risk perceived by each worker will be different, and this difference can be described by p_t^i in the model. p_t^irefers to the construction worker$i$'s risk perception coefficient at the moment of$l$, which reflects the tendency of individuals to overestimate or underestimate the risk. A value greater than 1 indicates that the agent$i$'s perceived risk is greater than the actual risk at time$l$. Workers affected by their own safety attitudes will change from actual risk (AR) to perceived risk (PR). The agent$i$'s perceived risk (PR_t^i) at time l is calculated as follows.

$$PR_t^i = p_i^t AR_i^t \quad (2)$$

$$p_i^t = p_i^{t-1} - \left(AT_i^t - AT_i^{t-1}\right) \quad (3)$$

AT_i^t is the agent i's safety attitude at time l . If the worker's safety attitude becomes higher, which means that the worker pursues risk-taking, then the risk perception coefficient will decrease.

(3) Perceptual reaction stage

After the construction workers perceive the risk, they begin to take action. The theory of risk steady state believes that the ability to perceive risks and their acceptability of danger are the two important perspectives for workers to make behavioral decisions (Wilde, 2010). In other words, if the worker's perceived risk greater than their own risk acceptance threshold, the worker will take safe actions to avoid a safety accident. Considering the research of Choi et al. (Choi and Lee, 2017), in addition to factors derived from the workers themselves, the risk acceptance of workers is also affected by team norms and managerial norms. In equation (4), the workeri's risk acceptance (RA_i^t) includes

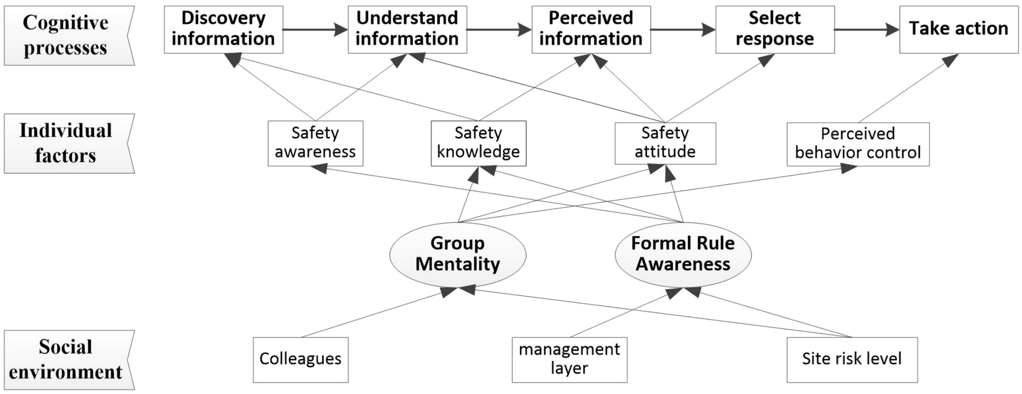

FIGURE 2 | Analysis on influencing factors of construction workers' cognitive process.

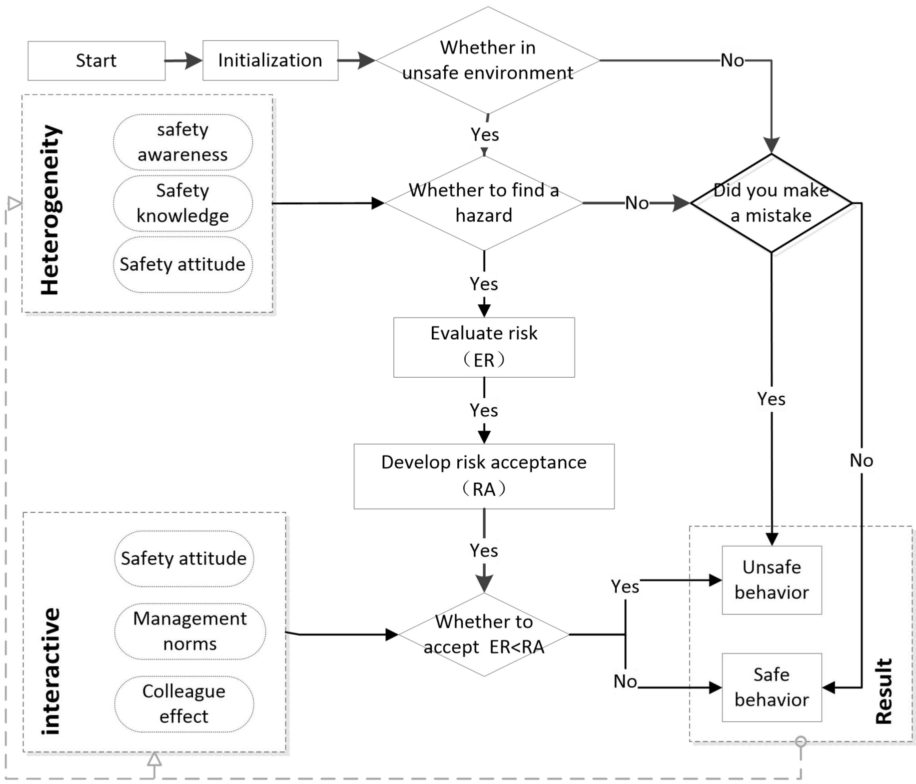

FIGURE 3 | Agent behavior rules.

factors such as workers' safety attitudes, colleague effects, and formal rules.

$$RA_i^t = (1 - a_i)\left[(1 - c_i)\, AT_i^t + c_i Co_t^i\right] + a_i WN_i^t + \varepsilon \qquad (4)$$

WN_i^t is management norms, ε is the error effect that is not considered in the model, Co_i^t is the colleague effect, which is specifically reflected in the risk acceptance of surrounding colleagues obtained by workers observing the behavior of co-workers, and is defined as the risk acceptance of the 20 nearest co-workers around the worker i at time$l$. a_i is workers' formal rule awareness, $c_i$is conformity intention, indicates the workers' willingness to follow the crowd, and refers to the degree to which workers learn and emulate the unsafe behaviors of their surrounding workers.

(4) Selective reaction stage

In this process, workers will compare perceived risks and risk acceptance to decide whether to take safe or unsafe behaviors.

When the perceived danger is less than the risk acceptance, it means that the danger perceived by the worker is within his acceptable degree, the worker will think that the risk is not very high and take risks to favor unsafe behavior; When perceived danger exceeds risk acceptance, the worker believes that the situation is beyond their acceptance and will adopt safe behaviors to ensure their own safety, As shown in formula (5).

$$UB_i^t = \begin{cases} 0 \ PR_i^t > RA_i^t \\ 1 \ RA_i^t < PR_i^t \end{cases} \tag{5}$$

UB_i^tindicates whether the worker i will take unsafe behaviors at time$l$, $UB_i^t = 1$represents the agent i will tend to take safe actions at time$l$, $UB_i^t = 0$represents the agent$i$ will prefer taking safe actions at time$l$.

When the worker's perceived risk is within the threshold and the worker has taken unsafe behavior, a safety accident may occur, at this time$Accident_i^t = 1$. It is also possible that a safety incident did not happen by luck, then$Accident_i^t = 0$. The probability of an accident is calculated according to formula (6).

$$Accident_i^t = \begin{cases} 1 \qquad UB_i^t = 1, rand(0,1) < SR \\ 0 \ UB_i^t = 1, rand(0,1) > SR, or, UB_i^t = 0 \end{cases} \tag{6}$$

If a safety accident occurs after a worker has taken an unsafe behavior, the occurrence of the accident will affect the worker's safety attitude. There is also a situation that even if the worker decides to take a safe behavior, but because of mistakes or unable to control their own behavior, it will also lead to accidents. If workers take unsafe behaviors and accidents occur, workers' safety attitudes will decrease; if workers take unsafe behaviors but no accidents occur, then workers' safety attitudes will increase; if workers take safe behaviors, their safety attitudes will not changes. The formula for calculating the safety attitude is as formula (7).

$$AT_i^{t+1} = \begin{cases} AT_i^t, UB_i^t = 0 \\ AT_i^t - 1, UB_i^t = 1\text{且} \ Accident_i^t = 1 \\ AT_i^t + 1, UB_i^t = 1\text{且} \ Accident_i^t = 0 \end{cases} \tag{7}$$

Experimental Initialization

The environment of construction workers can be divided into operating environment and management environment generally. The strength of the on-site operating environment risk has a strong connection to construction workers' behavior and decision. Research shows that safety cognition may be related to the work situation of workers and their own safety attitudes. This article considers on-site risk levels. However, as there is no unified classification standard for the classification of environmental risks on construction sites, quantitative analysis is not made in this article. According to the actual construction period of the project, 200 workers are simulated for 200 days. Different values were used to test the influence of these parameters repeatedly, and the results are analyzed and compared to discover objective laws. The settings of other variables in the simulation as shown in **Table 1**.

Workers with a safety attitude greater than 0.5 indicate that workers have a risk-taking tendency and are more inclined to take unsafe or risk-taking behavior in order to complete the work as soon as possible. The risk perception coefficient is used to reflect the evaluation of construction workers' perception of risk and whether they can control risk. After repeated tests, it is determined to obey a normal distribution of 0.4 to 1. In this simulation, the management norms follow a uniform distribution within a certain range. When function distribution is not clear, a uniform distribution is often the most appropriate. The values of 0.1 and 0.9 at the two different levels reflect the differences in the management system of managers, indicating that some managers have stricter norms and some are looser, which can more accurately reflect the actual conditions of the construction site. To explore changing law of the number of workers who take unsafe behaviors under different combinations of formal rule awareness (a_i) and conformity intention (c_i) to conform, the parameter definitions have different values. First, based on the simulation experiment of Byungjoo Choi et al. (Choi and Lee, 2018), the on-site risk level is described as three scenarios. The on-site risk SR is set to 0.45, which means that there is a 45% probability that construction workers are in a dangerous construction site environment. Second, the conformity intention is an important parameter for studying construction workers' social learning and safety cognition. Seungjun Ahn regards its countdown as the time required for workers to fully recognize the behavior of co-workers and regard it as a formal norm. $c_i$take 0.05 (Low), 0.4 (Middle), and 0.9 (High). $c_i = 0.05$means that construction workers can quickly regard the performance and behavior of co-workers as a code of conduct. A value of 0.9 means that construction workers rely more on the risks they perceive and are less likely to be influenced to believe in their own judgments. Finally, the range of formal rule awareness is from 0.1 to 0.9. It is assumed that construction workers pay more attention to formal rules than internal rules in the formation of risk acceptance. For example, a formal rule awareness of 0.9 means that the relative importance of formal standards and personal standards is 9:1.

TABLE 1 | Initial value setting of relevant variables.

Variables	Value
Simulation days (D)	200
Number of construction workers (N)	200(20*10)
Actual risk(*AR*)	N(μ, σ^2)
Initial value of workers' safety awareness(*SA*)	0.8
Initial value of workers' safety knowledge(*SK*)	0.8
Initial value of workers' safety attitude (AT)	0.5
Initial value of risk perception coefficient (p)	U (0.4, 1)
Management norms (*WN*)	U(0.1, 0.9)

RESULTS AND DISCUSSION

This model uses Net logo 6.1.1 for simulation. In order to accurately reflect the evolution of workers' unsafe behavior, each result is run 30 times to achieve an accurate and stable state. In this study, the average unsafe behavior rate or the

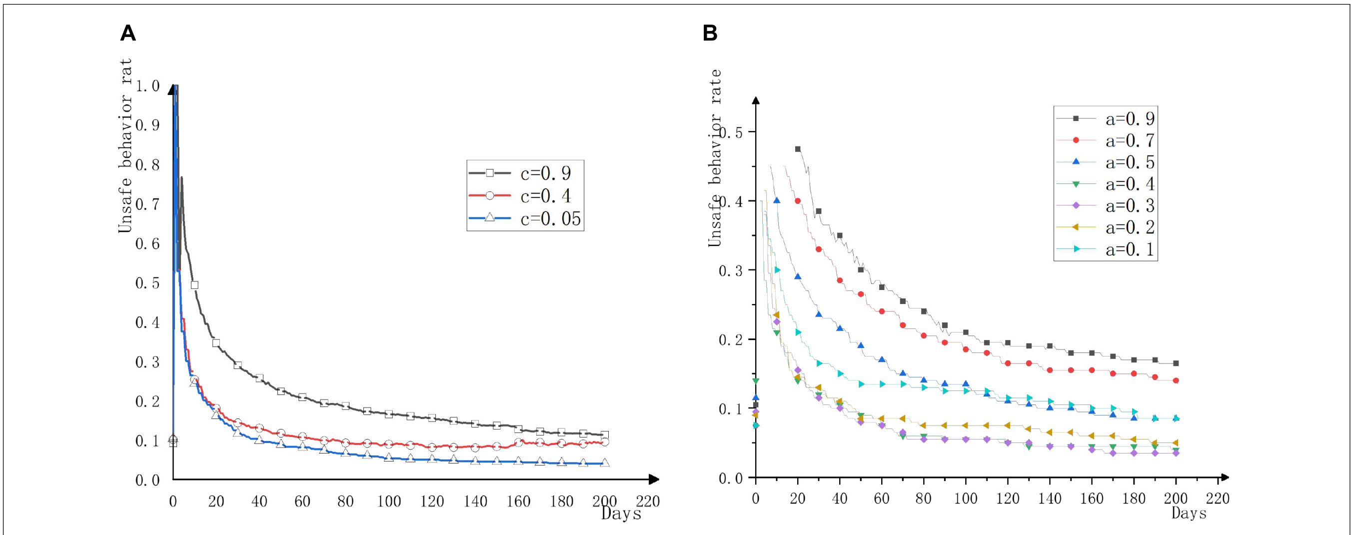

FIGURE 4 | Evolution Trend of unsafe behavior rate under the action of conformity mentality and formal rule awareness. **(A)** Evolution trend of unsafe behavior rate under the action of conformity mentality alone. **(B)** Evolution trend of unsafe behavior rate under the action of formal rule awareness alone.

number of unsafe behaviors in the construction team is used to characterize the influence degree of conformity mentality and formal rule awareness. **Figure 4A** shows the change trend of unsafe behavior rate when the construction workers' conformity intention is divided into 0.05, 0.4, and 0.9. The horizontal axis represents the number of simulation days. It can be seen from the figure that in the process of workers' conformity intention from low to high, the curve of the average unsafe behavior rate of the group gradually rises, and workers tend to adopt unsafe behaviors. Individuals have a high conformity intention to conform to the crowd, and the effect of group conformity is significant. Workers can quickly adapt and adjust their own behavioral norms according to others' behavioral norms so that the two can reach agreement. This is manifested in workers as that these workers are not so "stubborn," they easily and quickly regard the co-workers' behavior as a code of conduct, and the construction team is relatively unstable. Research by Ligia Cremene shows that in the case of complex topologies (scale-free, small world), a high level of conformity seems to be beneficial to dishonest behavior (Cremene and Cremene, 2021). The modern construction environment is becoming more and more complex, and the interaction and connection between the agents are becoming more and more complicated. The traditional simple topology model is gradually not suitable for the building safety simulation model, and the complex topology is more likely to be suitable for modern dynamics. Data from multiple simulation experiments shows that this is closely related to the number of people in the team who initially engage in unsafe behavior. If the initial unsafe number of people in the experiment is large and the conformity mentality level of workers is high, the unsafe behavior rate will increase significantly; if the level of the worker conformity mentality is low, even if the initial number of unsafe behaviors is large, the unsafe behavior rate curve will not show a great upward trend. This is because workers appear to be more "stubborn" and are not easily influenced by others, and the increase in unsafe behavior is not obvious. Therefore, in a construction team with a high level of conformity effect, the composition structure of the construction team and the behavior tendency of the workers must be strictly controlled. Even a small number of unsafe behaviors may have a negative effect on the safety management of the construction team. Managers need to guard against workers with strong conformity mentality, pay attention to the role of psychological adjustment, create a good safety atmosphere through safety education, adjust and guide workers' psychology, and control the occurrence of unsafe behaviors of the construction team.

Figure 4B shows the changing trend of unsafe behavior rate during the process of construction workers' formal rule awareness rising from 0.1 to 0.9. Because when the conformity intention of workers is high, workers are more dependent on the behavioral norms of workers, which will cover the influence of formal rule awareness. Therefore, the formal rule awareness should be tested when the level of management norms is high and the conformity mentality of workers is low. As shown in **Figure 4B**, the influence of formal rule awareness has a critical point, and the average unsafe behavior rate of the group shows a trend of decreasing first and then increasing. When the formal rule awareness is within the range of [0.1, 0.4], the unsafe behavior rate of workers decreases significantly with the improvement of formal rule awareness, continues to increase the value of formal rule awareness, and the unsafe behavior rate of workers increases. The formal rule awareness of construction workers increases within the range of [0.1, 0.4], the closer the internal rules perceived by the workers are to the formal rules. The relationship between workers' internal rules and formal rules can improve workers' unsafe behavior, but the gap should not be too large. Thinking that internal rules are particularly important or that formal rules are particularly important are not conducive to workers making correct behavior decisions. In the study of Ahn et al. (2013), the value of a_i was not set

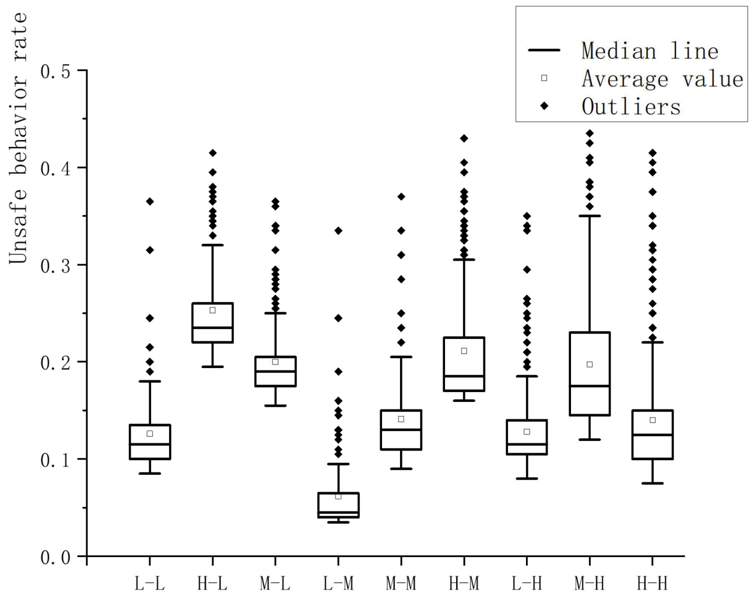

FIGURE 5 | The evolution of unsafe behaviors of workers in the context of different levels of conformity mentality and formal rule awareness.

too high. In this experiment, the awareness of formal rules was too high, and the difference between the internal rules of the workers and the formal rules was too great, which is not conducive to the construction safety behavior. When workers' formal rule awareness is low, there are great differences between workers' perceived internal rules and external rules. According to the basic structure of control theory proposed by Charles S. Carver—feedback loop to reduce differences (Carver and Scheier, 1982), when there are differences between internal rules and formal rules, workers tend to reduce differences to accept unsafe behaviors due to self-regulation. Therefore, from the perspective of formal rule awareness, workers have unsafe behavior in the cognitive process due to the convergence of internal rules and formal rules, which is also verified by the experimental results. Managers should pay attention to the regulatory role of rule awareness in the cognitive process. When the rule awareness is improved within a certain range, the rate of unsafe behavior has been effectively controlled. In view of this, managers should grasp the key factors in the cognitive process and use the self-regulation of construction workers to adapt to formal norms. As the formal rule awareness needs to play a greater role when the management standard is high, while regulating workers' formal rule awareness, the management must also formulate corresponding rules and regulations, which cannot be lower than the average level of management standard, and otherwise it is difficult to play the corrective role of formal rule awareness.

Figure 5 shows the evolution data of workers' unsafe behavior under different levels of conformity mentality and formal rule awareness combination scenarios (for example, L-L means low conformity mentality, low formal rule awareness). The outliers in **Figure 5** all belong to the right skewed distribution at the upper end of the upper limit. The optimal situation is L-M, the unsafe behavior rate is below 0.1, and the worst situation is H-L, and the unsafe behavior rate reaches 0.25. It can be seen from **Figure 5** that in the L-L, L-M, and L-G scenarios, the average unsafe behavior rate is lower, which is a better scenario. At this time, the worker conformity mentality level is at a low level; the average unsafe behavior rate of H-L, M-L, and H-M is higher. It belongs to a poor situation, and the worker's formal rule awareness is at a low level at this time, which conforms to the law obtained in **Figure 4**. It can be seen from H-L, H-M, and H-H in **Figure 5** that when the conformity mentality of workers is high, the original group unsafe behavior rate should be on the high side. With the improvement of workers' formal rule awareness, the number of safe behaviors gradually increases. The behavior rate shows a downward trend, which shows that the formal rule awareness has a corrective effect on workers' unsafe behaviors.

Figure 6 shows the regional map formed by the two-way action of formal rule awareness and conformity mentality of construction workers in different cycles (t = 50, 100, 150, and 200). In the figure, the abscissa axis represents the conformity intention, and the ordinate axis represents the formal rule awareness, which forms the evolution result of the team unsafe behavior rate when the formal rule awareness and conformity mentality act in both directions, and presents a certain hierarchy and regularity.

Not long after the experiment started (T = 50), the formal rule awareness and conformity mentality had not yet taken effect. With the interaction between them, workers' behavior began to change. As the simulation progresses, the area of area A continues to expand and become more concentrated, which means that in different cycles in the team, the formal rule awareness and the conformity mentality have different effects. In Area A, the rate of unsafe behaviors is low, and workers' safety awareness remains at a high level. As the formal rule awareness interacts with the conformity mentality, and the value scenarios in Area A

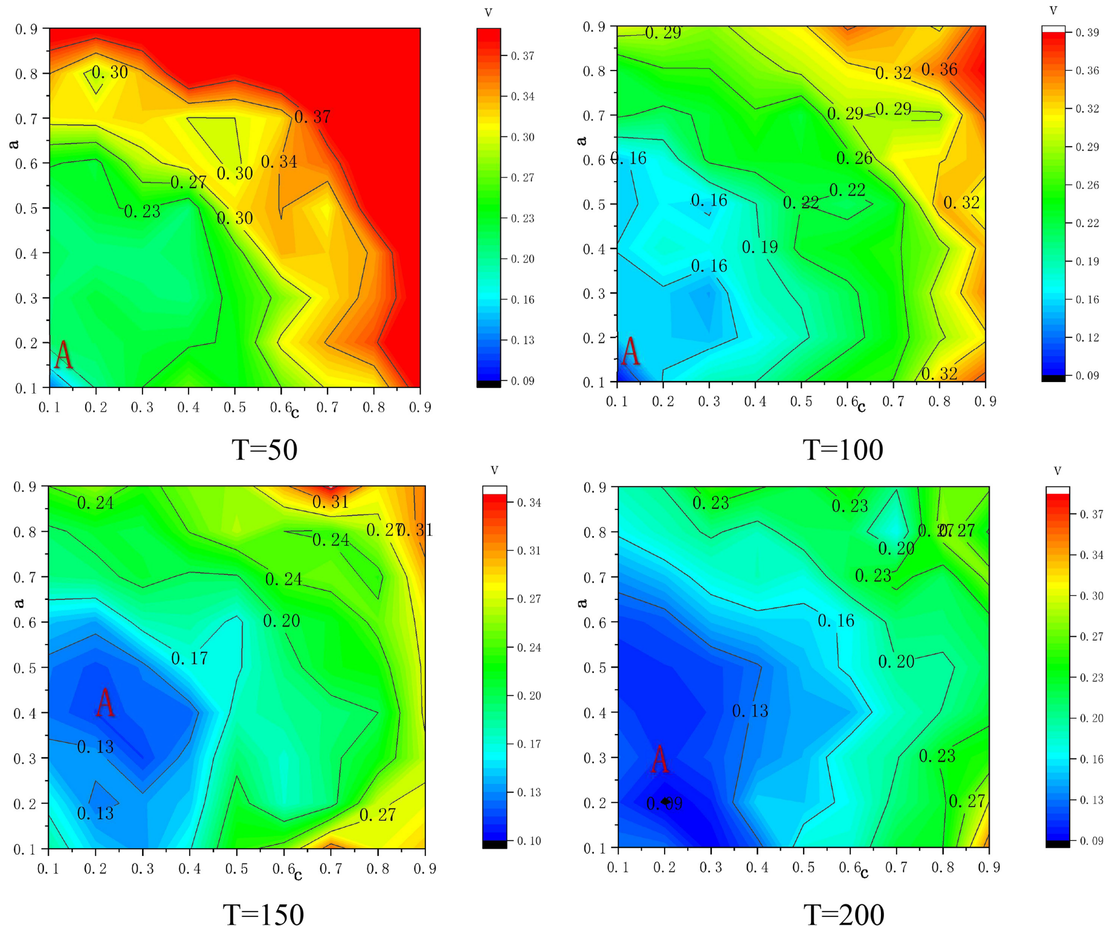

FIGURE 6 | The role of formal rule awareness and conformity mentality in different cycles.

are far away, the rate of unsafe behaviors is higher. According to this, in the full-cycle safety production management of building construction, the appropriate degree of interaction between formal rule awareness and conformity mentality can be selected according to the overlapping areas of the area A of different cycles in **Figure 6**, to achieve the life-cycle safety management of the construction project. When the experiment reaches a steady state, it can be found that as the conformity mentality continues to increase, the unsafe behavior rate presents an upward trend. At this time, the formal rule awareness increases between [0.1, 0.4], and the unsafe behavior rate continues to decrease, so the formal rule awareness can correct unsafe behaviors caused by workers' cognitive failure, which is consistent with the conclusions in **Figure 5**.

The above simulation experiments show that when workers cannot accurately perceive risks under certain construction site environmental risks, managers should reasonably control the initial personnel structure of the team according to the characteristics of workers, prevent workers with strong herd mentality, attach importance to workers' self-regulation, give play to the role of formal rule awareness in correcting deviations in the cognitive process, and create a good safety atmosphere through safety education to regulate and guide workers' psychology. Adjusting workers' will to follow the crowd, which can make workers turn to take safety actions and reduce the occurrence of safety accidents. Secondly, in order to achieve higher management objectives, we should adjust the interaction between formal rule awareness and conformity will, make the workers in the state of L = M (low conformity will and medium formal rule awareness), make the workers' internal rules close to the formal rules and reduce the risk acceptance threshold by formulating reasonable formal rules and safety education, Correct the cognitive failure of workers, so as to take safe behaviors, avoid risks and reduce unsafe behaviors. In the life cycle management of engineering project, the overlapping scope of formal rule awareness and conformity mentality can effectively control the rate of unsafe behavior of the team and ensure the effectiveness of safety management.

CONCLUSION

This study uses multi-agent modeling to study the evolution process of construction workers' unsafe behavior. According to the theories of complex adaptive system, safety cognition and risk perception, the safety cognition rules of unsafe behavior of construction workers are set up, the relationship between safety cognition and unsafe behavior is analyzed, and then a series of simulation experiments are carried out. The model is simulated by different combinations of formal rule awareness and conformity mentality. The simulation results show that: Workers' unsafe behaviors are inseparable from cognitive failures. Workers' formal rule awareness and their conformity intention will affect the cognitive process; The higher the level of conformity mentality of workers, the more likely it is to trigger group unsafe behaviors. If the initial number of unsafe behaviors in the team is relatively large, it will aggravate the occurrence of safety accidents; Workers' formal rule awareness can only play a greater role when management standards are high, and it has a corrective effect on workers' safety cognition; Under certain construction site environmental risks, the interaction between the formal rule awareness and the conformity mentality within the appropriate range (L-M) is conducive to the realization of the full life cycle management of the engineering project. On the basis of multi-agent modeling, this paper combs the influence relations of various factors in the cognitive process, combines workers' cognitive process and risk perception, constructs the agent interaction and cognitive model under the two-way effect of formal rule awareness and conformity mentality, promotes the application of safety cognition in regulating construction workers' safety behavior. Combining computational experiment and cognitive process, the unsafe behavior of workers is studied from the perspective of behavioral evolution. Through simulation, the scene environment of workers' activities, main agent decision-making and group behavior emergence are reproduced. On this basis, the evolution law is analyzed, which to some extent solves the problems such as difficult modeling in the system and difficult to describe the dynamic interaction process of the main agent, and promotes the process of combining psychological theory with computational simulation method to study practical problems. The findings of this study simulate workers' cognitive decision-making process by multi-agent modeling, which helps managers understand the motivation and reasons of workers' behavior from the perspective of individual psychology and consciousness, formulate workers' safety training system and safety management system, strengthen the management of construction team, and effectively reduce the occurrence of unsafe behavior.

The limitations of this paper can be improved in future research. The description of dynamic changes of management norms or more specific management strategies, worker heterogeneity and learning can be complicated in future research. Through the simulation experiment, the dynamic relationship between unsafe behavior, safety cognition and risk perception of construction workers is improved, which provides a certain direction for the management to formulate the management system from the perspective of safety cognition.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The study was conducted after approvals were granted from the school of management, Jiangsu University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

XB contributed to conception, modeling, ran the experiment, and writing. ZL and YS contributed to conception and writing. YX contributed to writing and checking. All authors contributed to this article and agreed to the submitted version.

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Safety Stressors and Construction Workers' Safety Performance: The Mediating Role of Ego Depletion and Self-Efficacy

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As an important influencing factor of construction workers' safety performance, safety stressor has received increasing attention. However, no consensus has been reached on the relationship between different types of safety stressors and the subdimensions of safety performance, and the mechanism by which safety stressors influence safety performance remains unclear. This study proposed a multiple mediation model with ego depletion and self-efficacy as mediators between safety stressors and workers' safety performance. Data were collected from 335 construction workers in China. Results demonstrated that: (1) the three types of safety stressors (i.e., safety role ambiguity, safety role conflict, and interpersonal safety conflict) all had negative effects on workers' safety performance (i.e., safety compliance and safety participation); (2) self-efficacy mediated all the relationships between the three safety stressors and safety performance; (3) ego depletion only mediated part of the relationships between the three safety stressors and safety performance; and (4) only part of the multiple-step mediating effects through ego depletion and self-efficacy were supported. This study made contributions by shedding light on the mechanism by which safety stressors influence workers' safety performance and providing more empirical evidence for the relationship between various safety stressors and the subdimensions of safety performance. Additionally, targeted strategies for improving workers' safety performance were proposed according to the findings.

Keywords: construction worker, safety performance, safety stressor, ego depletion, self-efficacy

INTRODUCTION

Construction is one of the most dangerous industries which incur thousands of fatal and nonfatal injuries every year (Dzeng et al., 2016; Hasanzadeh et al., 2019; Sanni-Anibire et al., 2020; Moosa and Oriet, 2021). According to the Occupational Safety and Health Administration (2019), the fatal injuries in the U.S. construction industry stood at 1008 in 2018. The corresponding figure of China was even more striking with 1752 death toll in the construction industry in the first half of 2018 (Ministry of Emergency Management of the People's Republic of China, 2018). These incidents or accidents threaten the health and safety of site personnel and bring huge losses to construction enterprises (Nodoushan et al., 2020; Zhang et al., 2020; Al-Kasasbeh et al., 2021; Zhou et al., 2021). Therefore, improving construction safety performance has always been a research hotspot. However, despite improvements over the years, safety performance in the construction industry remains unsatisfactory (Gunduz et al., 2018).

Traditionally, safety performance has been measured by lagging indicators such as the number of accidents, injury rate and death toll (Qi et al., 2022). Nevertheless, these lagging indicators may not provide the insights necessary to avoid future accidents (Grabowski et al., 2007). Hence, scholars proposed that leading indicators should be used to express safety performance (Sinelnikov et al., 2015; Shaikh et al., 2021). Leading indicators are measures of actions taken to prevent accidents (Toellner, 2001). Construction workers' performance is a typical leading indicator and has been considered as one of the ideal indicators of safety performance (Hinze et al., 2013) in that their unsafe behavior is the frequent, direct, and main cause of accidents (Jiang et al., 2015; Li et al., 2015; He et al., 2020). Eliminating workers' unsafe behaviors is the biggest challenge to improve safety performance (Fang et al., 2020), and safety performance can be achieved through workers' safety behaviors (Al-Bsheish et al., 2017). Therefore, this study defines safety performance as workers' safety behaviors. Based on the job performance theory (Borman and Motowidlo, 1993), Neal and Griffin (1997) proposed two subdimensions of safety performance, i.e., safety compliance and safety participation. Safety compliance refers to "the core safety activities that need to be carried out by individuals to maintain workplace safety," while safety participation refers to "behaviors such as participating in voluntary safety activities or attending safety meetings" (Griffin and Neal, 2000).

The premise of improving safety performance is to understand factors that influence safety performance (Sampson et al., 2014). Occupational stressors have been widely recognized to have a significant influence on employees' job performance (Lu et al., 2016; Leung et al., 2017; Alroomi and Mohamed, 2021). Due to the complex, dynamic and uncertain site environment, construction workers have long been exposed to numerous occupational stressors (Mohr and Wolfram, 2010; Leung et al., 2016; Liang et al., 2021). Safety stressors and safety performance are occupational stressors and job performance within the safety context. Hence, the relationship between safety stressors and safety performance has attracted academic attention. Related studies have focused on examining the relationships between different safety stressors and the two subdimensions of safety performance, and evaluating the moderating effects of supervisor support, psychological capital and safety specific trust on these relationships (Sampson et al., 2014; Wang et al., 2018, 2020). In general, they believed that safety stressors had negative effects on workers' safety performance. However, the underlying mechanism by which safety stressors affect workers' safety performance remains unclear, which is not conducive to improving workers' safety performance from the perspective of safety stressors.

The relationship between occupational stressors and job performance varies according to the type of stressors and the dimension of job performance examined (Cavanaugh et al., 2000; Lepine et al., 2005; Rosen et al., 2010). In the construction industry, role ambiguity, role conflict and interpersonal conflict are the most common and representative occupational stressors (Melia and Becerril, 2007; Brockman, 2014; De Silva et al., 2017; Wu et al., 2019). Hence, this study is going to explore the effects of safety role ambiguity, safety role conflict and interpersonal safety conflict on workers' safety compliance and safety participation. Safety role ambiguity occurs when safety-related expectations and information (e.g., safety responsibilities, safety goals and safety behaviors) of workers' roles are unclear (Rizzo et al., 1970; Jackson and Schuler, 1985; Wang et al., 2020). Safety role conflict reflects that workers receive incompatible safety role expectations (Rizzo et al., 1970; Rosen et al., 2010; Akgunduz, 2015). Interpersonal safety conflict corresponds to disagreements over safety issues between organization members (Gittleman et al., 2010; Wang et al., 2020). According to the conservation of resources theory, job demands-resources model and ego depletion theory, coping with safety stressors may consume workers' resources, thus increasing workers' ego depletion and decreasing their self-efficacy. In turn, ego depletion and self-efficacy have been considered to affect safety performance (Dai et al., 2015; Adjekum, 2017). Therefore, this study explored the mechanism by which safety role ambiguity, safety role conflict and interpersonal safety conflict influence construction workers' safety compliance and safety participation from the potential mediating effects of ego depletion and self-efficacy. In addition, we also provided suggestions for the management of construction workers' unsafe behavior based on the research results.

THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

Theoretical Background

Conservation of Resource Theory

Conservation of resources (COR) theory was proposed by Hobfoll (1989) to explain individuals' responses to stressors. According to this theory, individuals tend to acquire, maintain, cultivate and conserve resources (Hobfoll et al., 2018). Resources refer to "anything perceived by the individual to help attain his or her goals" (Halbesleben et al., 2014, p. 1,338). Individuals use their key resources to cope with stressful situations in the current environment and they also actively construct and protect the existing resources to deal with possible stressful situations in the future. Self-control and self-efficacy are typical individual resources (Hagger et al., 2010; Guarnaccia et al., 2018; Zhong et al., 2020). Self-control refers to the self-suppression of harmful reaction tendency and self-stimulation of beneficial reaction tendency through cognitive, emotional and behavioral strategies (Hagger et al., 2010; Righetti and Finkenauer, 2011). Self-efficacy is the belief in one's ability to successfully perform a task or achieve a goal (Bandura, 1977). Addressing occupational stressors depletes individuals' resources, and the loss of resources can trigger burnout (Prapanjaroensin et al., 2017). As a result, individuals will take action to avoid resource losses (Halbesleben et al., 2014). What's more, when facing the desperate situation of resource exhaustion, the defense mechanism of individuals' self-protection will be activated and they may engage in irrational behaviors.

JD-R Model

Based on the COR theory, Demerouti et al. (2001) developed the job demands-resources (JD-R) model which divided job characteristics into job demands and job resources. Job demands are the requirements of work on individuals' physical, psychological, social and other aspects and the factors that require individuals to pay corresponding efforts or costs to complete the work (De Jonge and Dormann, 2006). In brief, job demands are "bad things" that consume individuals' energy at work, such as role conflict, role ambiguity and job insecurity (Bakker et al., 2005). On the contrary, job resources are "good things" at work, referring to physical, psychological, social and organizational resources that help individuals to achieve their goals, reduce job demands, and stimulate personal growth and development (Schaufeli and Bakker, 2004). There are two psychological processes that work influence employees: the stress process and the motivation process (Schaufeli, 2017). The stress process corresponds to the process that excessive job demands and lacking job resources induce burnout which in turn results in negative outcomes such as poor performance. Burnout is characterized by emotional exhaustion, depersonalization, and reduced self-efficacy (Demerouti et al., 2001). The motivation process is akin to the process that abundant job resources improve employees' work engagement and thus lead to positive effects, such as high job performance.

Ego Depletion Theory

Ego depletion is akin to the state of diminished self-control resulting from the depletion of self-control resources (Hagger et al., 2010). According to the ego depletion theory proposed by Baumeister et al. (1998), engaging in the act of self-control consume resources, which will impair the performance of subsequent self-control task. Ego depletion explains the failure of individuals' volitional activities such as self-control and regulation (Baumeister et al., 2007). Ego depletion occurs when individuals perform self-control actions such as coping with stress (Baumeister et al., 2007; Schmidt et al., 2007). Conversely, ego depletion will reduce employees' work engagement and output (Muraven and Baumeister, 2000; Schmeichel et al., 2003). Employees thus exhibit less organizational citizenship behavior and conduct more abnormal behaviors such as workplace deviation behavior and unsafe behavior (Dewall et al., 2007; Barnes and Wagner, 2009; Christian and Ellis, 2011; Lin et al., 2016).

Hypotheses Development

The Relationship Between Safety Stressors and Safety Performance

Previous research found that hindrance job stressors had negative effects on job performance (Lepine et al., 2005; Wallace et al., 2009; Lu et al., 2016; Abbas and Raja, 2019). Safety role ambiguity, safety role conflict and interpersonal safety conflict are all hindrance job stressors that hinder workers' personal growth and goal attainment and thus these safety stressors may influence workers' safety performance (Grebner et al., 2010; Kim and Beehr, 2018). Rosen et al. (2010) proposed that the effect of stressors on performance varies with the type of stressors and the dimension of performance examined. Sampson et al. (2014) found that all safety stressors that they examined were significantly associated with decreased safety participation while only safety role ambiguity and safety role conflict were significantly related to decreased safety compliance. Based on the work of Sampson et al. (2014), Wang et al. (2018) investigated the relationship between three types of safety stressors (i.e., safety role ambiguity, safety role conflict and interpersonal safety conflict) and construction workers' safety performance. Their results indicated that the three types of safety stressors all had negative effects on construction workers' safety participation while only safety role ambiguity had significant influence on workers' safety compliance. Where after, Wang et al. (2020) examined the relationship between the three types of safety stressors and two types of safety citizenship behaviors (i.e., safety participation). Their findings suggested that safety role ambiguity, safety role conflict and interpersonal safety conflict had negative effects on proactive safety behaviors while only interpersonal safety conflict had negative effects on prosocial safety behaviors. The above studies have not reached a consensus on the relationship between the three types of safety stressors and the two subdimensions of safety performance. Therefore, this study still examined the relationship between the three types of safety stressors and the two sub-dimensions of safety performance. We hypothesize:

H1: Safety role ambiguity (H1a), safety role conflict (H1b) and interpersonal safety conflict (H1c) have negative effects on workers' safety compliance.

H2: Safety role ambiguity (H2a), safety role conflict (H2b) and interpersonal safety conflict (H2c) have negative effects on workers' safety participation.

The Mediating Role of Ego Depletion

The Relationship Between Safety Stressors and Ego Depletion

According to the ego depletion theory, engaging in self-control activities consumes the limited self-control resources, thus leading to ego depletion (Baumeister et al., 1998, 2007). A large number of studies have shown that job stressors, especially hindrance stressors (e.g., role ambiguity and role conflict), increase the depletion of individuals' self-control resources, and thus increase ego depletion (Sonnentag and Jelden, 2009; Grebner et al., 2010; Diestel and Schmidt, 2011; Prem et al., 2016; Che et al., 2017; Xia et al., 2020b). The three types of safety stressors involved in the current study are typical hindrance stressors that have negative effects on construction workers. To overcome safety stressors, workers have to use more self-control and self-regulation resources than they would under normal circumstances (Xia et al., 2020b). Therefore, safety stressors may deplete workers' self-control resources and induce ego depletion. The three types of safety stressors may deplete workers' self-control resources in different ways. First, faced with ambiguous safety roles, workers need to exert self-control to activate information-seeking and resource-seeking behaviors. Second, in the situation of safety role conflict, workers must make behavioral decisions after weighing different expectations, which calls self-control resources. Third, interpersonal safety conflict is easy to induce workers' negative emotions, such as anger, anxiety, and depression (Spector and Jex, 1998; Jiang et al., 2013; Ten Brummelhuis et al., 2014). Coping with these negative emotions requires effort in self-control (Muraven and Baumeister, 2000; Bertrams and Pahl, 2014; Prem et al., 2016). All the three types of safety stressors can increase the depletion of workers' self-control resources and thus increase workers' ego depletion. Hence, we hypothesize:

H3: Safety role ambiguity (H3a), safety role conflict (H3b) and interpersonal safety conflict (H3c) have positive effects on ego depletion.

The Relationship Between Ego Depletion and Safety Performance

Under the state of ego depletion, individuals' willingness and ability to self-control decrease, which may lead to the failure of subsequent self-control activities (Baumeister et al., 1998, 2007). Self-control is the process by which people overcome impulse, habit or automated response, and consciously control their behaviors, including inhibiting impulse to incorrect behaviors and activating correct behaviors (Tangney et al., 2004; Hagger et al., 2010; Hale and Borys, 2013). Workers' self-control is essential for maintaining a high level of safety behaviors (Probst and Brubaker, 2001). Failures of self-control lead to an increase in risky behaviors or unsafe behaviors, thereby impairing safety performance (Salmon et al., 2014; Dai et al., 2015). For example, minor violations are the prepotent response of workers and may be reinforced into habitual violations that are carried out in a non-thinking and automated way (Reason et al., 1998; Hinsz et al., 2007). As workers' self-control ability and willingness decline, their resistance to the impulse of automated behaviors also declines. Therefore, they cannot resist the habitual impulse to violate safety regulations, resulting in increased violations and reduced safety compliance. In addition, according to the COR theory (Hobfoll, 1989), workers are inclined to conserve their limited resources. Especially when they have consumed self-control resources, they would be more cautious about subsequent resource allocation. Trougakos et al. (2015) proposed that employees would devote their resources to fulfilling work tasks rather than extra-role organizational citizenship behaviors. Similarly, workers who experience ego depletion would devote less effort toward organizational citizenship behaviors, thus reducing safety participation. Accordingly, we hypothesize:

H4: Ego depletion has negative effects on safety compliance (H4a) and safety participation (H4b).

According to the COR theory and JD-R model, stress factors or job demands such as safety role ambiguity, safety role conflict and interpersonal safety conflict consume workers' resources. The ego depletion theory further suggests that workers need to invest more self-control resources when experiencing safety role ambiguity, safety role conflict and interpersonal safety conflict. The depletion of self-control resources puts workers into the state of ego depletion (Hagger et al., 2010). Workers' ability and willingness to engage in subsequent self-control activities decrease. Accordingly, workers may engage in more violations (e.g., unsafe behavior) or perform less organizational citizenship behavior (Barnes and Wagner, 2009; Lin et al., 2016). In brief, dealing with safety role ambiguity, safety role conflict and interpersonal safety conflict increase the possibility of workers' ego depletion which may damage safety performance. That is, ego depletion may mediate the relationship between safety stressors and safety performance. As a result, we hypothesize:

H5: Ego depletion mediates the relationships between safety stressors [safety role ambiguity (H5a), safety role conflict (H5b) and interpersonal safety conflict (H5c)] and safety compliance.

H6: Ego depletion mediates the relationships between safety stressors [safety role ambiguity (H6a), safety role conflict (H6b), interpersonal safety conflict (H6c)] and safety participation.

The Mediating Role of Self-Efficacy

The Relationship Between Safety Stressors and Self-Efficacy

The JD-R theory proposes that high job demands may lead to burnout (Demerouti et al., 2001). Reduced self-efficacy is the core characteristic of burnout (Maslach, 1982). Namely, job demands can lead to a decrease in self-efficacy. Role ambiguity, role conflict and interpersonal conflict are widely regarded as a kind of hindering job demands (Lorente Prieto et al., 2008; Ashill and Rod, 2011; Martinez-Corts et al., 2015; Kilroy et al., 2016; Kim and Beehr, 2018; Kim et al., 2020). Previous studies have also shown that role ambiguity, role conflict and interpersonal conflict were negatively correlated with individuals' self-efficacy (Jex and Gudanowski, 1992; Hartline and Ferrell, 1996; Chebat and Kollias, 2000; Eys and Carron, 2001; Karatepe et al., 2006; Li and Bagger, 2008; Tang and Chang, 2010; Kadir et al., 2017). We can infer that safety role ambiguity, safety role conflict and interpersonal safety conflict may contribute to the decrease of workers' self-efficacy. To be exact, safety role ambiguity means that workers lack sufficient information to properly assess their ability to perform safety tasks, thus inhibiting their ability to visualize their performance. This reduces workers' confidence in their ability to complete safety tasks (Bandura, 1977). Experiencing safety role conflict and interpersonal safety conflict can also reduce workers' self-efficacy because conflicting environment makes workers question their ability (Tang and Chang, 2010).

H7: Safety role ambiguity (H7a), safety role conflict (H7b) and interpersonal safety conflict (H7c) have negative effects on self-efficacy.

The Relationship Between Self-Efficacy and Safety Performance

Self-efficacy has been proposed to significantly and positively correlate with safety performance (Chen and Chen, 2014; Adjekum, 2017; Kim and Jung, 2019). Workers with a high level of self-efficacy show more initiative at work and are more willing to learn new skills, making more efforts to understand safety procedures as well as learning skills that are necessary for them to do their work safely (Chughtai, 2015), which may increase their awareness and ability to perform safety compliance. Likewise, workers who have more belief in self-efficacy are more confident in their ability to complete extra-role tasks (Parker, 2000). They are more likely to participate in safety activities and help colleagues, thus increasing safety participation. On the contrary, workers with low self-efficacy have less confidence in their ability to complete safety-related tasks. They do not trust that they could be more professional than others. Therefore, they are not inclined to voice their safety opinions and help colleagues with safety issues. Nor do they think they can learn more safety skills or understand more safety rules. As a result, workers who have less belief in self-efficacy may have poor safety performance.

H8: Self-efficacy has positive effects on safety compliance (H8a) and safety participation (H8b)

As safety stressors can reduce workers' self-efficacy and workers' self-efficacy positively correlate with their safety performance, we can infer that self-efficacy may mediate the relationship between safety stressors and safety performance. Thus, we hypothesize:

H9: Self-efficacy mediates the relationships between the three safety stressors [safety role ambiguity (H9a), safety role conflict (H9b), interpersonal safety conflict (H9c)] and safety compliance.

H10: Self-efficacy mediates the relationships between the three safety stressors [safety role ambiguity (H10a), safety role conflict (H10b), interpersonal safety conflict (H10c)] and safety participation.

The Multiple-Step Mediating Effects Through Ego Depletion and Self-Efficacy

Previous studies show that self-efficacy is also affected by ego depletion (Chow et al., 2015; Graham and Steven, 2015). Self-efficacy is not an entirely automated process but one that requires self-control, since individuals need to ignore or deal with doubt and fear to maintain confidence (DeBono and Muraven, 2013). Workers who experience ego depletion may find it necessary to conserve resources (Job et al., 2010). They would reduce their self-efficacy for subsequent self-control to conserve resources (Chow et al., 2015). Furthermore, workers who suffer ego depletion may have more negative evaluations of themselves and more negative predictions of their subsequent performance (DeBono and Muraven, 2013). In other words, ego depletion makes workers believe that they are inefficacious (Chow et al., 2015), thus decreasing their self-efficacy in subsequent tasks (Fischer et al., 2007; Graham and Steven, 2015; Graham et al., 2017).

H11: Ego depletion has negative effects on self-efficacy.

As stated above, the three types of safety stressors may have positive effects on workers' ego depletion. Ego depletion influences workers' self-efficacy which, in turn, impacts their safety performance (Adjekum, 2017). Therefore, there may exist multiple-step mediation effects of safety stressors on safety performance through ego depletion and then self-efficacy. In other words, safety stressors induce workers' ego depletion which decreases their self-efficacy, thus reducing their safety performance.

H12: Safety role ambiguity (H12a), safety role conflict (H12b), and interpersonal safety conflict (H12c) impair construction workers' safety compliance through the multiple-step mediating effect of ego depletion and self-efficacy.

H13: Safety role ambiguity (H13a), safety role conflict (H13b), and interpersonal safety conflict (H13c) impair construction workers' safety participation through the multiple-step mediating effect of ego depletion and self-efficacy.

The conceptual model that integrates all hypotheses stated above is shown in **Figure 1**.

METHODS

Participants and Data Collection Procedures

A questionnaire survey was conducted to collect data for hypothesis tests. Before the formal survey, a pre-research was conducted in a construction project in Chengdu, China. 15 construction workers from this project participated in the pre-research. The preliminary questionnaire was slightly modified to make it easier to understand based on the feedback from the 15 construction workers. The formal survey was carried out at seven construction sites in Chongqing, China, from October 2018 to March 2019. A total of 400 questionnaires were sent out and taken back on the spot. Questionnaires with more than 5% unanswered items [$N = 40$; according to Seo (2005) and Xia et al. (2020a)] and those answered arbitrarily ($N = 25$; e.g., there is an obvious pattern of repetition in the answers) were manually identified and excluded. Therefore, the final valid sample size was 335 (83.75% valid response rate).

Respondents' demographic characteristics are shown in **Table 1**. As for gender distribution, most respondents were male, accounting for 87.5% ($n = 293$), while female respondents accounted for only 12.5% ($n = 42$). All respondents were over the age of 20 and those aged 41–50 made up the largest proportion (45.70%), almost half of the total. 78% ($n = 263$) of the surveyed workers had been working in the construction industry for more than 5 years. In terms of educational background, most participants were poorly educated, with 73.1% ($n = 245$) of respondents completing only primary or secondary school.

Measures

The constructs of this study consist of safety stressors, ego depletion, self-efficacy, and safety performance. The scales for measuring these variables were adopted and modified from previous studies. All measurement items were rated with a five-point Likert scale ranging from 1 to 5.

Safety Stressors

Consistent with the research of Sampson et al. (2014), Wang et al. (2018), and Wang et al. (2020), 18 items were adopted

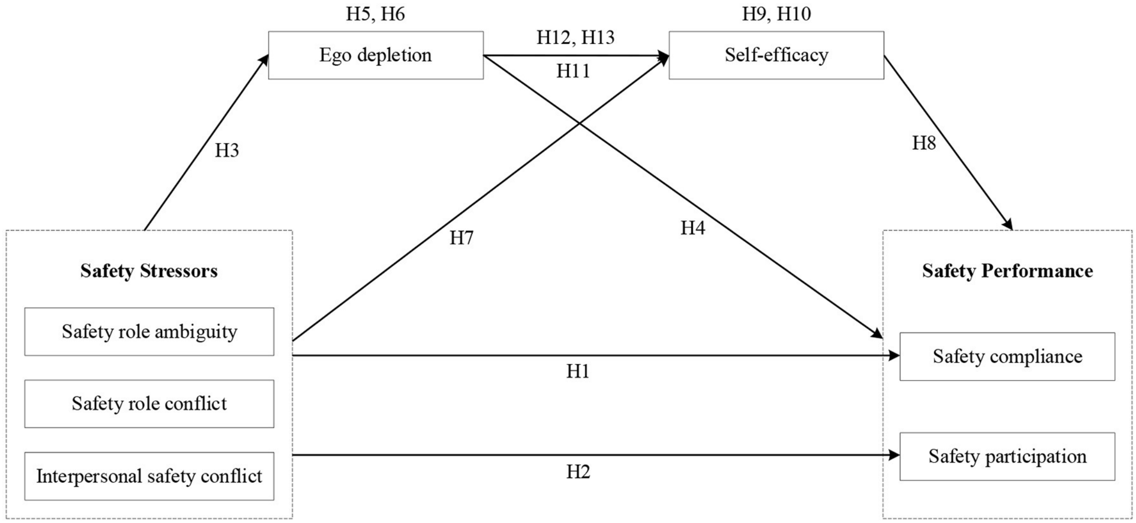

FIGURE 1 | The conceptual model.

TABLE 1 | Demographic characteristics of the respondents (*N* = 335).

Characteristics	Items	Frequency	Percentage (%)
Gender	Male	293	87.5
	Female	42	12.5
Age	20–30	73	21.80
	31–40	77	23.00
	41–50	153	45.70
	51–60	31	9.30
	More than 60	1	0.30
Work experience	<5 years	72	21.50
	5–10 years	119	35.50
	11–15 years	65	19.40
	16–20 years	54	16.10
	21–25 years	21	6.30
	26–30 years	4	1.20
Educational background	Primary school or below	107	31.90
	Secondary school	138	41.20
	High school	35	10.40
	Junior college	28	8.40
	Undergraduate or above	27	8.10

and modified to measure the three types of safety stressors, i.e., safety role ambiguity (SRA, five items), safety role conflict (SRC, nine items), and interpersonal safety conflict (ISC, four items). Sample items of the three sub-scales included "There are not clear, planned safety goals and objectives for my job," "I have to ignore a rule or policy to carry out an assignment safely," and "I get into arguments about safety with others at work," respectively. The scales of safety role ambiguity and safety role conflict were rated based on the level of agreement ranging from 1 (strongly disagree) to 5 (strongly agree), while the scale of interpersonal safety conflict was rated based on the frequency of occurrence varying from 1 (never) to 5 (extremely often).

Ego Depletion

The measurement scale of ego depletion (ED) was adopted and modified from Johnson et al. (2014). 10 items were used to measure construction workers' ego depletion, including items like "I feel drained." Items of the ego depletion scale were rated ranging from 1 (strongly disagree) to 5 (strongly agree).

Self-Efficacy

The measurement of self-efficacy (SE) was referred to the general self-efficacy scale developed by Schwarzer et al. (1997). A sample item of the 10-items scale is "I can always manage to solve difficult problem if I try hard enough." Participants were asked to score each item using the number of 1 (strongly disagree) to 5 (strongly agree).

Safety Performance

The measurement scale of safety performance used in this study was developed by Griffin and Hu (2013), with four items measuring safety compliance (SC) and four items measuring safety participation (SP). Measuring items included "I use the correct safety procedures for carrying out my job," "I help my coworkers when they are working under risky or hazardous conditions," and so on. All items were rated from 1 (strongly disagree) to 5 (strongly agree).

Data Analysis Procedures

First, SPSS 22.0 was used for descriptive statistical analysis of the questionnaire data, through which the mean, standard deviation (SD) and correlation coefficients of the variables were obtained. Second, reliability analysis and validity analysis were employed to evaluate the quality of the measurement model. Reliability was assessed by Cronbach's alpha value of variables. Validity analysis included convergent validity test and discriminant validity test.

TABLE 2 | Means, SD, and correlation coefficients among variables.

Variables	Mean	SD	1	2	3	4	5	6	7
1. SRA	3.77	0.85	**0.783**						
2. SRC	3.68	0.85	0.458*	**0.693**					
3. ISC	2.29	0.85	0.211**	0.209**	**0.712**				
4. ED	3.43	0.86	0.205**	0.341**	0.396**	**0.709**			
5. SE	3.34	0.84	−0.459**	−0.493**	−0.435**	−0.364**	**0.673**		
6. SC	4.10	0.99	−0.571**	−0.410**	−0.427**	−0.192*	0.457**	**0.851**	
7. SP	3.73	1.02	−0.536**	−0.322*	−0.397**	−0.184**	0.345**	0.552**	**0.785**

*$p < 0.05$, **$p < 0.01$.

Diagonal bold font indicates the square root of AVE. The lower triangle presents Pearson's correlation coefficients between variables.

Then, a structural equation model was constructed to test the research hypotheses. In line with Baron and Kenny (1986), a three-step method was applied to examine the condition for establishing mediation. The first step was to examine the effect of independent variables on dependent variables (testing H1 and H2). In the second step, the influence of independent variables on meditators and the effect of mediators on dependent variables were examined (testing H3, H4, H7, and H8). The last step was to develop a structural equation model of the multiple mediation model to examine the mediation effects (testing H5, H6, H12, and H13). Bias-corrected (BC) bootstrap method was used to define the confidence intervals (CI) for examining the significance of the indirect effects.

RESULTS

Descriptive Statistics

The mean and standard deviation (SD) of variables, and the correlation coefficients among variables were shown in **Table 2**. Safety role ambiguity, safety role conflict, and interpersonal safety conflict were negatively related to safety compliance and safety participation. Safety role ambiguity, safety role conflict and interpersonal safety conflict were positively related to ego depletion. Safety role ambiguity, safety role conflict and interpersonal safety conflict were negatively related to self-efficacy. Ego depletion was negatively related to self-efficacy, safety compliance and safety participation. Self-efficacy was positively related to safety compliance and safety participation.

Reliability and Validity Testing

The quality of the measurement model was assessed by reliability and validity testing. Reliability was tested with Cronbach's alpha value. As shown in **Table 3**, Cronbach's alpha value of variables ranged from 0.799 to 0.912, reaching the accepted threshold value of 0.7 (Nunnally, 1978). Hence, it can be concluded that the measurement model had good reliability. Both convergent validity and discriminant validity were tested in this study. Convergent validity was assessed by the indices of standard factor loading (SFL), construct reliability (CR), and average variance extracted (AVE). Results of the convergent validity testing are presented in **Table 3**. To ensure good convergent validity, the SFL values should exceed 0.5 (Hair et al., 2006), while the CR values and AVE values should be >0.6 and 0.5, respectively (Fornell and Larcker, 1981). It can be seen from **Table 3** that SFL were all significant ($p < 0.001$) and most indicators were above 0.5 (only one indicator being less than 0.5). CR values ranged from 0.804 to 0.913. And most of the AVE values reached the threshold of 0.5. Therefore, the convergence reliability of the measurement model was acceptable. Discriminant validity was examined by comparing the square root of AVE and the correlation coefficients between variables. The square root of a variable's AVE should be higher than the correlation coefficients involving that variable (Fornell and Larcker, 1981). The Pearson's correlation coefficients between variables and the square root of AVE are shown in **Table 2**. All the square root of AVE was higher than the involving correlation coefficients, revealing that the discriminant validity of each construct was acceptable.

Hypothesis Testing

Structural equation modeling (SEM) was employed in the present study to test hypotheses since SEM is very effective in controlling measurement errors when estimating both the direct and indirect effects (Cheung and Lau, 2008). According to the suggestion of Baron and Kenny (1986), a causal steps strategy was used to examine the condition for establishing mediation.

First, the direct effects of the independent variables on the dependent variables were examined. The path coefficients among safety stressors and safety performance are shown in **Figure 2**. Safety role ambiguity, safety role conflict, and interpersonal safety conflict negatively influenced safety compliance, which supported H1a, H1b, and H1c. Safety role ambiguity, safety role conflict, and interpersonal safety conflict had negative effects on safety participation, thus supporting H2a, H2b, and H2c. All the independent variables were found to have significant effects on the dependent variables. Therefore, the first condition for establishing mediation was supported.

Second, the direct effects of the independent variables on the mediators and the effect of the mediators on the dependent variables were examined. **Figure 3** shows the path coefficients among safety stressors and ego depletion, and **Figure 4** shows the path coefficients among safety stressors and self-efficacy. Safety role ambiguity, safety role conflict, and interpersonal safety conflict positively affected ego depletion, supporting H3a, H3b, and H3c. Safety role ambiguity, safety role conflict, and interpersonal safety conflict had negative effects on self-efficacy,

TABLE 3 | Results of reliability and validity testing.

Variables	Indicators	SFL	S.E.	Est./S.E.	*p*-value	Cronbach's alpha	CR	AVE
SRA	SRA1	0.819	0.023	36.179	***	0.886	0.888	0.613
	SRA2	0.706	0.031	22.517	***			
	SRA3	0.801	0.024	33.234	***			
	SRA4	0.846	0.021	40.948	***			
	SRA5	0.735	0.029	25.335	***			
SRC	SRC1	0.627	0.037	16.982	***	0.891	0.892	0.480
	SRC2	0.731	0.029	24.980	***			
	SRC3	0.592	0.039	15.195	***			
	SRC4	0.707	0.031	22.787	***			
	SRC5	0.737	0.029	25.489	***			
	SRC6	0.672	0.034	19.929	*			
	SRC7	0.731	0.029	24.965	***			
	SRC8	0.715	0.031	23.494	***			
	SRC9	0.708	0.031	22.819	***			
ISC	ISC1	0.616	0.042	14.734	***	0.799	0.804	0.507
	ISC2	0.742	0.035	21.508	***			
	ISC3	0.752	0.034	22.217	***			
	ISC4	0.731	0.036	20.540	***			
ED	ED1	0.698	0.031	22.703	***	0.5	0.908	0.502
	ED2	0.753	0.026	28.477	***			
	ED3	0.808	0.022	36.679	***			
	ED4	0.681	0.032	21.304	***			
	ED5	0.422	0.047	8.917	***			
	ED6	0.726	0.029	25.411	***			
	ED7	0.744	0.027	27.370	***			
	ED8	0.612	0.037	16.597	***			
	ED9	0.829	0.020	40.506	***			
	ED10	0.727	0.028	25.525	***			
SE	SE1	0.821	0.022	37.338	***	0.86	0.891	0.453
	SE2	0.715	0.030	23.725	***			
	SE3	0.591	0.039	15.231	***			
	SE4	0.698	0.031	22.234	***			
	SE5	0.707	0.031	22.960	***			
	SE6	0.625	0.037	17.077	***			
	SE7	0.672	0.033	20.120	***			
	SE8	0.511	0.044	11.698	***			
	SE9	0.721	0.030	24.254	***			
	SE10	0.622	0.037	16.940	***			
SC	SC1	0.797	0.023	34.481	***	0.92	0.913	0.725
	SC2	0.852	0.019	45.537	***			
	SC3	0.876	0.017	52.282	***			
	SC4	0.878	0.017	52.360	***			
SP	SP1	0.676	0.034	19.742	***	0.863	0.865	0.617
	SP2	0.826	0.024	34.340	***			
	SP3	0.798	0.026	31.210	***			
	SP4	0.831	0.024	34.915	***			

*$p < 0.05$, ***$p < 0\ .001$.

which supported H7a, H7b, and H7c. **Figure 5** presents the path coefficients among ego depletion, self-efficacy, and safety performance, and **Figure 6** presents the path coefficients among self-efficacy and safety performance. Ego depletion negatively influenced safety compliance and safety participation, which meant that H4a and H4b were supported. Self-efficacy had

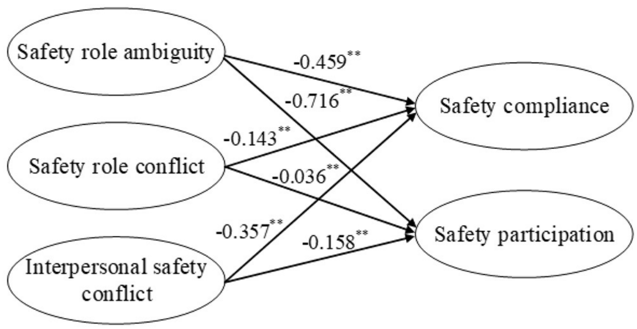

FIGURE 2 | Direct effects of safety stressors on safety performance. **$p < 0.01$.

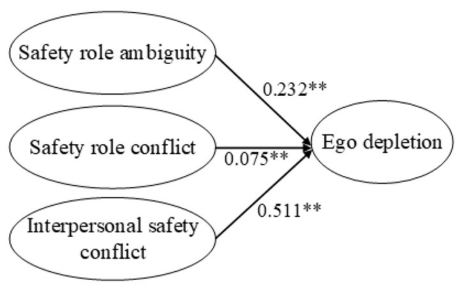

FIGURE 3 | Direct effects of safety stressors on ego depletion. **$p < 0.01$.

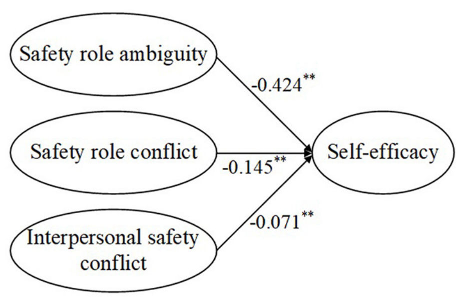

FIGURE 4 | Direct effects of safety stressors on self-efficacy. **$p < 0.01$.

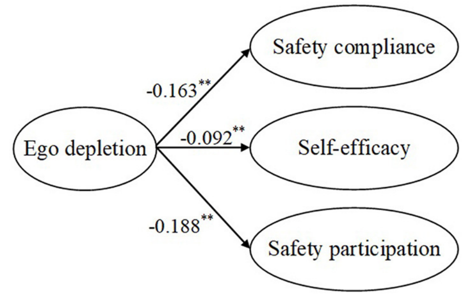

FIGURE 5 | Direct effects of ego depletion on safety performance and self-efficacy. **$p < 0.01$.

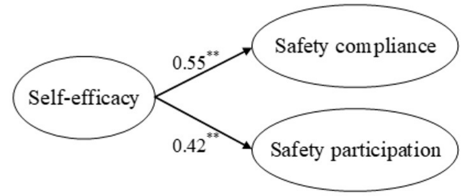

FIGURE 6 | Direct effects of self-efficacy on safety performance. **$p < 0.01$.

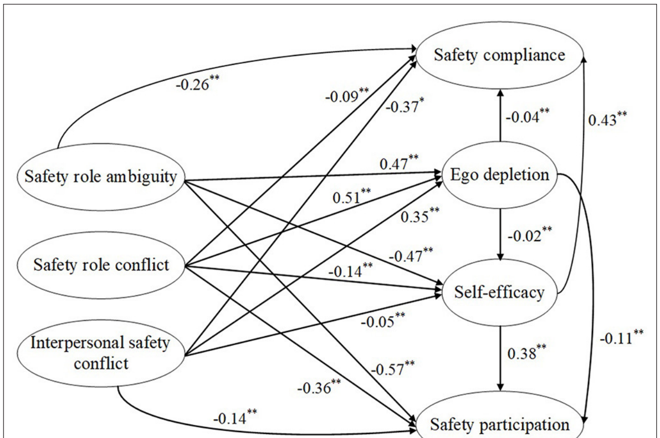

FIGURE 7 | Structural equation model of the conceptual model. *$p < 0.05$; **$p < 0.01$ (two-tailed); $N = 335$.

positive effects on safety compliance and safety participation, thus supporting H8a and H8b. Ego depletion was found to negatively affect self-efficacy, which supported H11. All independent variables had significant effects on the mediators and the mediators had significant effects on the dependent variables. Hence, the second condition of mediation was also supported, suggesting that ego depletion and self-efficacy may act as mediators in the relationship between safety stressors and safety performance.

A structural equation model of the multiple mediation model was developed to test the mediation effects, and the results are shown in **Figure 7**. The overall fit index (χ^2 = 1,317.14, df = 968, χ^2 / df = 1.36, CFI = 0.952, TLI = 0.949, RMSEA = 0.033, SRMR = 0.045) indicated that the overall fitness of the structural model was good. Following the suggestion of Cheung and Lau (2008), we used the bias-corrected (BC) bootstrap method to define the confidence intervals (CI) for examining the significance of the indirect effects. The bootstrap sample size and the confidence intervals were set as 1,000 and 95%, respectively. **Table 4** shows the standardized direct effects, indirect effects, and total effects of the hypothesized mediation model. Interpersonal safety conflict had significant indirect effects on safety compliance through ego depletion, which meant that ego depletion mediated the relationship

TABLE 4 | Standardized direct effects, indirect effects, and total effects of the conceptual model.

	Estimate	S.E.	*P*-value	95% bias-corrected CI	
				Lower	Upper
Standardized direct effects					
SRA—SC	−0.26	0.03	**	0.01	0.51
SRC—SC	−0.09	0.08	**	0.06	0.24
ISC—SC	−0.37	0.02	*	0.61	0.14
SRA—SP	−0.57	0.05	**	0.29	0.87
SRC—SP	−0.36	0.01	**	0.23	0.17
ISC—SP	−0.14	0.03	**	0.10	0.39
Standardized indirect effects					
SRA—ED—SC	−0.02	0.05	0.32	−0.06	0.13
SRA—SE—SC	−0.20	0.10	**	0.04	0.44
SRA—ED—SE—SC	−0.26	0.02	0.19	−0.15	0.32
SRA—ED—SP	−0.05	0.05	0.43	−0.04	0.17
SRA—SE—SP	−0.18	0.06	**	0.03	0.39
SRA—ED—SE—SP	0.00	0.02	0.22	−0.05	0.02
SRC—ED—SC	−0.02	0.05	0.23	−0.12	0.08
SRC—SE—SC	−0.06	0.04	**	0.03	0.17
SRC—ED—SE—SC	−0.05	0.02	0.29	−0.02	0.06
SRC—ED—SP	−0.13	0.06	**	0.07	0.15
SRC—SE—SP	−0.11	0.04	*	0.04	0.16
SRC—ED—SE—SP	−0.08	0.02	**	0.05	0.13
ISC—ED—SC	−0.05	0.04	**	0.03	0.09
ISC—SE—SC	−0.08	0.05	**	0.06	0.13
ISC—ED—SE—SC	−0.03	0.01	**	0.02	0.05
ISC—ED—SP	−0.19	0.05	*	0.16	0.22
ISC—SE—SP	−0.09	0.04	**	0.05	0.12
ISC—ED—SE—SP	−0.07	0.01	0.19	0.01	0.09
Standardized total effects					
SRA—SC	−0.74	0.02	**	0.32	0.88
SRC—SC	−0.18	0.02	**	0.03	0.25
ISC—SC	−0.53	0.01	**	0.16	0.59
SRA—SP	−0.80	0.02	**	0.58	1.01
SRC—SP	−0.68	0.01	**	0.14	0.72
ISC—SP	−0.49	0.01	**	0.09	0.54

$^{*}p < 0.05$, $^{**}p < 0.01$.

between interpersonal safety conflict and safety compliance (supporting H5c). Safety role conflict had significant indirect effects on safety participation through ego depletion, suggesting that ego depletion mediated the relationship between safety role conflict and safety participation (supporting H6b). The indirect effect of interpersonal safety conflict on safety compliance through ego depletion was significant, supporting H6c (i.e., "ego depletion mediated the relationship between interpersonal safety conflict and safety compliance"). Safety role ambiguity influenced safety compliance through self-efficacy, thus supporting H9a. Safety role conflict also affected safety compliance through self-efficacy, thus supporting H9b. Interpersonal safety conflict had a significant indirect effect on safety compliance through self-efficacy, which meant that self-efficacy mediated the relationship between interpersonal safety conflict and safety compliance (supporting H9c). Safety role ambiguity had significant indirect effects on safety participation through self-efficacy, which suggested that self-efficacy mediated the relationship between safety role ambiguity and safety participation (supporting H10a). The indirect effect of safety role conflict on safety participation through self-efficacy was significant, supporting H10b (i.e., "self-efficacy mediated the relationship between safety role conflict and safety participation"). The indirect effect of interpersonal safety conflict on safety participation through self-efficacy was significant, supporting H10c (i.e., "self-efficacy mediated the relationship between interpersonal safety conflict and safety participation"). H12c (i.e., "interpersonal safety conflict impaired construction workers' safety compliance through the multiple mediating effects of ego depletion and self-efficacy") was supported as interpersonal safety conflict had significant indirect effects of on safety compliance through ego depletion and self-efficacy. Additionally, H13b (i.e., "safety role conflict impaired construction workers' safety participation through the multiple mediating effects of ego depletion and self-efficacy") was supported since the indirect effect of safety role conflict on safety participation through ego depletion and self-efficacy was significant. However, the rest of the estimated indirect effects were insignificant ($p > 0.05$), thus rejecting H5a, H5b, H6a, H12a, H12b, H13a, and H13c. In addition, the direct effects of the three safety stressors on safety compliance and safety participation were significant (see **Table 4**), suggesting that ego depletion and self-efficacy only partially mediated the relationship between safety stressors and safety performance.

DISCUSSION

Prior studies have discussed the effects of safety role ambiguity, safety role conflict, and interpersonal safety conflict on workers' safety performance, but they did not agree on the relationship between these safety stressors and safety performance. They have examined the moderating effects of supervisor support, psychological capital, and safety specific trust on these relationships, but they did not explore the mediating variables in these relationships. Given this, this study investigated the relationships between the three safety stressors and construction workers' safety performance. Moreover, this study also examined the mediating role of ego depletion and self-efficacy in the relationships between the three safety stressors and construction workers' safety performance.

Theoretical Implications

First, safety role ambiguity, safety role conflict and interpersonal safety conflict had negative effects on both safety compliance and safety participation. This finding was not completely consistent with previous studies. Sampson et al. (2014) and Wang et al. (2018) also found that safety role ambiguity, safety role conflict and interpersonal safety conflict negatively influenced construction workers' safety participation. However, only parts of the relationships between the three safety stressors and safety compliance were supported in their studies. The discrepancy between our results and the results of Sampson et al. (2014) may be attributed to the different subjects we surveyed. The participants of Sampson et al. (2014) were pipefitters from the United States while our respondents were construction workers from China. Both job functions and cultural differences may have influenced the results. As for the inconsistent results between this study and the study of Wang et al., it may be because we used different safety performance measurement scales. Wang et al. (2018) applied the scale developed by Griffin and Neal (2000). We employed the scale modified by Griffin and Hu (2013). Although this finding is not consistent with the research results of Sampson et al. (2014) and Wang et al. (2018), it is congruent with the general job stressors-performance research (Jex, 1998; Wallace et al., 2009; Rosen et al., 2010; Eatough et al., 2011). Safety role ambiguity, safety role conflict and interpersonal safety conflict were hindrance stressors that could reduce job performance (Lepine et al., 2005; Abbas and Raja, 2019). Safety role ambiguity created uncertainty for workers and weakened their motivation to maintain and improve safety performance (Beehr and Bhagat, 1985; Celik, 2013). Safety role conflict reflected that workers receive incompatible safety role expectations (Sampson et al., 2014). The most common example is that the organization requires workers to both comply with safety rules and work faster, but sometimes the two goals conflict. Abiding by safety rules is often time-consuming and requires extra efforts, which may affect production and annoy colleagues. To avoid criticism, workers tend to eschew such safe behaviors (Fang et al., 2016), which may decrease safety performance. Interpersonal safety conflict could bring negative emotions (Barki and Hartwick, 2004) which may lead to workers' deliberate violations, thereby reducing safety compliance. When conflicts arise between workers and their colleagues, they tend to avoid them and be reluctant to help them with safety issues (Curcuruto et al., 2019), namely, hindering their safety participation.

Second, ego depletion mediated parts of the examined relationships between safety stressors and safety performance. Safety role ambiguity, safety role conflict, and interpersonal safety conflict had significant positive effects on workers' ego depletion which meant that coping with these stressors consumed workers' self-control resources. Ego depletion, in turn, had negative effects on workers' safety compliance and safety participation. The ego depletion theory and COR theory provided explanations for this phenomenon. According to the ego depletion theory, ego depletion leads to the decrease of an individual's willingness and ability to subsequent self-control, resulting in fewer organizational citizenship behaviors and more unsafe behaviors (Baumeister et al., 1998, 2007; Dai et al., 2015). The COR theory suggests that individuals will be more cautious about resource allocation when they lack resources. Faced with heavy tasks and multiple work objectives, construction workers may allocate their limited self-control resources to more important tasks rather than in safety activities, resulting in reduced safety performance (Xia et al., 2019). Safety role ambiguity, safety role conflict and interpersonal safety conflict had significant effects on workers' ego depletion and ego depletion had significant effects on safety compliance and safety participation. However, ego depletion was found to only mediate the relationship between interpersonal safety conflict and safety compliance, the relationship between safety role conflict and safety participation, as well as the relationship between interpersonal safety conflict and safety participation.

Third, self-efficacy mediated all the examined relationships between safety stressors and safety performance. Safety role ambiguity, safety role conflict, and interpersonal safety conflict had negative effects on workers' self-efficacy. This finding could be explained by the JD-R model. Safety role ambiguity, safety role conflict, and interpersonal safety conflict were job demands (Bakker et al., 2005). High job demands could induce burnout and reduced self-efficacy was the core characteristic of burnout (Demerouti et al., 2001). Namely, these safety stressors negatively affected workers' self-efficacy. Self-efficacy was found to have positive effects on workers' safety compliance and safety participation, which was consistent with previous studies (Chen and Chen, 2014; Adjekum, 2017; Kim and Jung, 2019). Self-efficacious workers had better feelings of work control and motivation to work safely, which may foster their safety behaviors

(He et al., 2019). Safety role ambiguity, safety role conflict, and interpersonal safety conflict had significant effects on workers' self-efficacy and workers' self-efficacy had significant effects on workers' safety compliance and safety participation. Thus, we proposed that self-efficacy may mediate the relationships between safety stressors and safety performance. The results of the empirical study supported our hypothesis. The mediating effects of self-efficacy on the relationship between the three types of safety stressors and the two sub-dimensions of safety performance were all statistically significant. That is, safety role ambiguity, safety role conflict and interpersonal safety conflict could influence workers' safety performance through workers' self-efficacy.

In addition, ego depletion was found to have negative effects on workers' self-efficacy. This was because maintaining self-efficacy requires self-control (DeBono and Muraven, 2013). Workers' self-control resources reduced under the state of ego depletion, thus leading to decreased self-efficacy. Given this, we proposed that there existed multiple-step mediating effects through ego depletion and self-efficacy. However, the empirical results only supported part of our hypothesis about the continuous mediating effects. Only the multiple-step mediating effect of safety role conflict → ego depletion → self-efficacy → safety participation and the multiple-step of interpersonal safety conflict → ego depletion → self-efficacy → safety compliance were significant. It meant that safety role conflict may influence workers' safety participation through the multiple-step mediation of ego depletion and self-efficacy. And interpersonal safety conflict may affect workers' safety compliance through the multiple-step mediation of ego depletion and self-efficacy. Although only part of the continuous mediating effects was supported, it was still a useful attempt to explore the complex mechanism between safety stressors and safety performance.

Practical Implications

The results of this study also bring a lot of practical implications. First, in view of the negative effects of safety stressors on safety performance, construction enterprises should systematically identify safety stressors that workers may experience and take measures to eliminate them. Clear job description, safety information and safety role expectation should be provided to workers to avoid safety role ambiguity. Project managers should organize unified training for personnel from different organizations (e.g., sub-contractors) to form consistent safety cognition, thus reducing safety role conflict. In the meanwhile, cooperation should be emphasized to avoid interpersonal safety conflict. However, due to the unique characteristics of the construction industry, safety stressors may not be completely eradicated. Therefore, construction managers should also pay attention to regulating workers' psychological and physiological states. Workers should be provided with more chances to improve their safety knowledge and skills to improve their self-efficacy. Construction enterprises should also develop more reasonable work schedules to ensure that workers have enough rest time to mitigate ego depletion.

Limitations and Future Research

Limitations and suggestions for future research are as follows. First, this study measured safety stressors, ego depletion, self-efficacy, and safety performance with cross-sectional data. The cross-sectional data is not conducive to revealing the dynamic process in which safety stressors affect safety performance through ego depletion and self-efficacy. Longitudinal data are suggested for future studies. Second, the generalizability of results in this study might be limited because the sample data were obtained from construction workers in western China. Future studies may consider extending the sample to more regions and other high-risk industries. Third, this study only considered three safety stressors, and workers may face other safety stressors as well. As the relationship between job stressors and job performance changes with the type of stressors tested, future studies can explore more types of safety stressors and compare their effects. Finally, ego depletion only mediated part of the relationships between safety stressors and safety performance, and only part of the multiple-step mediating effects through ego depletion and self-efficacy were supported, suggesting that more examination should be conducted in the future.

CONCLUSION

This study investigated the effects of three types of safety stressors on construction workers' safety performance and the potential mediating role of ego depletion and self-efficacy in the relationship between these safety stressors and safety performance. The results showed that safety role ambiguity, safety role conflict and interpersonal safety conflict negatively affected workers' safety compliance and safety participation. Ego depletion was found to mediate the relationship between interpersonal safety conflict and safety compliance, the relationship between safety role conflict and safety participation, as well as the relationship between interpersonal safety conflict and safety participation. Self-efficacy mediated all the examined relationships between the three types of safety stressors and workers' safety performance. Additionally, we found that safety role conflict may influence workers' safety participation through the multiple-step mediation of ego depletion and self-efficacy, and interpersonal safety conflict may affect workers' safety compliance through the multiple-step mediation of ego depletion and self-efficacy. These findings help to clarify how safety stressors influence workers' safety performance and expand the scope of application of the ego depletion theory, job demands-resources model, and conservation of resources theory. This study also makes contributions by providing more empirical evidence for the relationship between safety stressors and safety performance. Moreover, this study has proposed many practical suggestions for improving workers' safety performance.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

GY: conceptualization, supervision, funding acquisition, and resources. QX: writing—original draft, writing—review and editing, formal analysis, and validation. LY: investigation, methodology, software, and visualization. JY, NX, YL, and TH: writing—review and editing. All authors contributed to the article and approved the submitted version.

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Driving Mechanism Model for the Supply Chain Work Safety Management Behavior of Core Enterprises—An Exploratory Research Based on Grounded Theory

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Guiding core enterprises to participate in supply chain work safety governance is an innovative mode of work safety control, which has an important impact on improving the work safety level of small and medium-sized enterprises in the supply chain. Through in-depth interviews, the grounded theory is adopted to explore the driving factors of work safety management behaviors of core enterprise. It is found that the work safety management behavior of the core enterprise is driven by both internal and external factors. External driving factors are the main category of institutional pressure composed of regulatory pressure, normative pressure, and cognitive pressure. Internal driving factors are divided into the main category of behavioral awareness and the behavioral capability of the core enterprises. The behavioral awareness is composed of responsibility sense, problem cognition and behavioral effect perception. The behavioral capability is composed of safety management strength and safety coordination capability. Institutional pressure, behavioral awareness, and behavioral capability all influence the work safety management behavior of core enterprise in supply chain significantly, but with different ways and paths. On this basis, the driving mechanism model of the above three main categories on the work safety management behavior in core enterprise supply chain is explored. The research can provide targeted policy ideas and implementation paths for the government to formulate effective guiding policies to promote the work safety management behavior of core enterprise.

Keywords: core enterprise, work safety management behavior in supply chain, driving factors, influence path, guiding policy, grounded theory

INTRODUCTION

There are serious supply chain work safety problems because of a large number of small and medium-sized manufacturing suppliers in the supply chain. In China, due to the backward technology and equipment, incomplete safety facilities and equipment, shortage of funds for work safety and chaotic safety management in most small and medium-sized manufacturing enterprises, the level of work safety is low and there are more serious occupational hazards and safety accidents.

On the one hand, small and medium-sized manufacturing enterprises are suspended and shut down for work safety issues, which directly affects the supply of core enterprises in the supply chain. For example, in September 2017, the auto parts manufacturer, Schaeffler Greater, was severely affected after Shanghai Jielong, which produced needle rollers, was ordered to stop production. On the other hand, the occurrence of occupational hazards or safety accidents in small and medium-sized manufacturing enterprises has a serious negative impact on the reputation and corporate value of core enterprises in the supply chain. For example, in 2009 employees of Apple's supplier were poisoned with n-alkane, as a result, Apple was criticized by environmental organizations and its reputation was damaged. In order to prevent the risk of supply chain safety accidents and occupational disease injuries, core enterprises need to adopt work safety management behaviors for their suppliers. Work safety management behavior in supply chain refers to the behavior that core enterprises to pay attention to the work safety of suppliers in the process of cooperation with them, and take corresponding measures to improve the safety management level of suppliers, prevent safety accidents and reduce occupational injury incidents (Ustailieva et al., 2012). According to Seuring and Müller (2008), compared with small and medium-sized manufacturing enterprises, core enterprises are in the leading position of the supply chain, with more advanced work safety concepts, technologies and management tools, so they might have the ability and obligation to take more social responsibility to improve the safety performance of their suppliers. At the same time, due to the order-dependent nature of small and medium-sized manufacturing enterprises, they would value the safety standard requirements and safety management of the core enterprises, and then adopt active work safety behavior.

The government and all sectors of society have gradually recognized the importance of work safety management behaviors in supply chain (Peckham et al., 2017; Zhou et al., 2020). In practice, some famous brand companies have made some useful attempts on work safety management behaviors in supply chain in China, such as multinational companies like Volkswagen, IKEA, Covestro, etc., and the local Chinese company, Huawei. However, most other companies are reluctant to participate in or do not know how to carry out work safety management in supply chain, i.e., there is not enough motivation for work safety management in supply chain. In traditional supply chain management, profit maximization is the goal of all enterprises. Although work safety management in supply chain can improve the safety level of the whole supply chain, it increases the operation cost of enterprises (Walters and James, 2011). On the one hand, there are few enterprises taking the initiative to extend their corporate social responsibility to carry out work safety management in supply chain, for example, they pay little attention to the work safety level of upstream and downstream enterprises in the supply chain and do not know enough about the benefits of safety management in supply chain. Moreover, the supplier chain of core enterprises is long and complex, so it is difficult to implement work safety management in supply chain (Alsamawi et al., 2017). On the other hand, the higher requirements of the core enterprises on the suppliers in terms of price, quality, and delivery of goods or services indirectly lead to heavier and more intensive workloads in the suppliers, especially small and medium-sized enterprises, which subsequently lead to adverse health and safety conditions for the workers (Bhattacharya and Tang, 2013; Siganporia et al., 2016). Therefore, strengthening the guidance of supply chain management for core enterprises and motivating them to adopt work safety management in supply chain has become an urgent research topic.

In order to encourage more core enterprises to adopt work safety management behaviors in supply chain, it is necessary to clarify the deep-seated factors driving core enterprises' work safety management in supply chain and their influencing paths on management behaviors. Therefore, this paper analyzes the motives of core enterprises to participate in safety management in supply chain from a behavioral perspective by using in-depth interviews and grounded theory, that is, the internal and external influencing factors of core enterprises' work safety management behaviors in supply chain and their mechanisms on enterprise management behavior decisions are explored in depth from a microscopic perspective. As a scientific and qualitative research method, grounded theory is suitable for studying the "how" and "why" questions. In this paper, open-ended questions are set up to discuss with supply chain managers the specific safety management behaviors in supply chain and the reasons for the management behaviors. Then, according to the interview data, the influencing factors of work safety management behavior in supply chain and the conduction relationship between influencing factors and management behavior are gradually extracted. This paper is an important supplement to work safety management in supply chain, and it has great policy guidance significance to guide more core enterprises to implement safety management in supply chain effectively.

LITERATURE REVIEW

Currently, there is little literature focusing on supply chain work safety management, but work safety of enterprises in social sustainability is the focus of social attention, and work safety element is also an important part of the sustainable development indicator of enterprises (Tsuda and Takaoka, 2006). Therefore, reviewing the literature on the drivers of supply chain sustainability management can provide a theoretical basis for the subsequent identification of the drivers of supply chain work safety management behavior in this paper. Supply chain sustainability management is essential for corporate to achieve sustainable competitive advantages (Dai et al., 2021). Current research in supply chain sustainability management focuses on environmental activities (Shibin et al., 2017; Boiral et al., 2019; Siems et al., 2021). However, it is shifting to focus on social requirements, because the social performance of the supply chain has a significant impact on stakeholders and supply chain performance (Mani et al., 2020). This paper will provide an overview of the drivers of supply chain sustainability management from both external and internal perspectives.

The External Factors

Sustainable management in supply chain mainly comes from the adjustment and shaping of external pressure, including institutional pressure, stakeholder pressure and possible sustainable risks. The institutional theory and stakeholder theory are involved. In 2011, Lee proposed a theoretical framework that combined institutional theory and stakeholder theory to explain how enterprises choose social responsibility strategies. It proposed that stakeholders obtain legitimacy and power from the institution. Institutional pressure influences the social behavior of enterprises through the stakeholder mechanism. The two are interdependent to form a specific external influence structure, which shapes how enterprises construct social responsibility strategies (Lee, 2011). Institutional theory studies different pressures and their impact on enterprise management decisions. Institutional pressure [including regulatory pressure, normative pressure and cognitive pressure (Scott, 1995)] is regarded as an important driving factor for enterprise supply chain management (Srivastava et al., 2021), because any enterprise must contend with institutional factors in management (Zeng et al., 2017). For example, government policies, laws and regulations may have a positive impact on sustainable supply chain management (Zhu et al., 2005). When the product raw material country lacks a policy and legal framework to manage the sustainability issues in complex supply chain, transnational corporations will evade supply chain governance (Boström and Micheletti, 2016). In addition, regulatory documents issued by non-governmental organizations can also encourage enterprises to fulfill social responsibilities (Phan and Baird, 2015). The external institutional environment not only shapes and strengthens the guiding principles of the organization, but also ensures that the organization abides by external rules, norms and values. Organizations respond to institutional pressure in different ways, such as compromise, avoidance, provocation or utilization (Oliver, 1991). In general, industries that are more regulated or its products and services directly affect people's lives, such as the food industry, pharmaceutical industry and automobile industry, will face higher institutional pressures. However, some studies show that it is not the industry but the specific behaviors within the industry that need to match higher institutional pressures, such as: child labor, pollution, unsustainable production methods, etc. (Srivastava et al., 2021). In turn, institutional pressure has promoted closer cooperation between buyers and sellers, such as developing green supply chain management to smoothly meet the requirements of mandatory regulations (Jazairy and von Haartman, 2020).

Stakeholders can mobilize public opinion to support or oppose the sustainability performance of the organization. From the perspective of resource dependence, stakeholders influence organizational behavior by influencing the acquisition of key resources, that is, they manipulate the flow of resources to the organization (Frooman, 1999). Sustainability has transcended the boundaries of the organization, so stakeholders put pressure on the sustainable development of the entire supply chain (Cantele and Zardini, 2020). Since larger enterprises are more likely to be scrutinized by stakeholders, they are more willing to transfer some of the pressure to supply chain partners (Parmigiani et al., 2011). Assistance from non-governmental organizations can help core enterprises improve their supply chain sustainable management capabilities (Stekelorum et al., 2020). With the help of third-party organizations, enterprises can obtain resources that cannot be obtained independently (Crespin-Mazet and Dontenwill, 2012) and establish social networks, that is, strategic bridging (Stafford et al., 2000). According to the relational theory (Dyer and Singh, 1998), enterprises operate in a relationship network, enabling them to create value that they cannot create independently (Lavie, 2006). In fact, the relationship among organizations will lead to the development of new resources, and new resources will become a competitive advantage (Garcia-Perez-de-Lema et al., 2017). The motivation of sustainable management of the enterprise supply chain is also affected by customers (Kot, 2018; Mani et al., 2020), such as pressure and support from customers, including technical support (Hoogendoorn et al., 2015), knowledge improvement (Touboulic and Walker, 2015), and enhancement of its legitimacy (El Baz et al., 2016).

Some scholars put forward the sustainable risk, that is, failure to comply with stakeholders' sustainability requirements may cause sustainability risks, including consumer boycotts, reputation damage, labor disputes, economic losses or legal proceedings, further damaging the financial performance of the enterprise and its supply chain (Hossan Chowdhury and Quaddus, 2021). For example, brand such as Nike, Adidas, Disney, and C&A are facing consumer resistance and close scrutiny by stakeholders due to the disclosure of sweatshop workers in the upstream supply chain (Busse et al., 2016). In some supply chain members, good sustainability practices may be ineffective due to poor sustainability practices of other supply chain members (which causes risks). Because of the knock-on risk, the core enterprise should be responsible for the behavior of the decentralized supply chain enterprises (Van Tulder et al., 2009; Wilhelm et al., 2016). Lacking proper sustainability governance may lead to poor sustainability practices among supply chain partners, bring risks to the entire supply chain, damage the overall reputation of the organization supply chain, and reduce performance (Faruk et al., 2001). In the supply chain, two concepts should be noted: interruption and vulnerability. Supply chain interruption risk = f (interruption, vulnerability) (Hossan Chowdhury and Quaddus, 2021), which is also an important driving factor for core enterprises to implement sustainable supply chain management. Seuring and Müller (2008) analyzed 191 papers on Sustainable Supply Chain Management (SSCM) published from 1994 to 2007, and summarized the following trigger factors of SSCM: legal requirements, customer requirements, maintaining competitive advantage, environmental and social pressure groups, reputation maintenance. However, there are correlations and crossovers among these triggers, and the classification is not clear. For example, if there are reports of social or environmental issues

TABLE 1 | Basic information of in-depth interview.

Enterprise	Business	The recording duration	Total characters recorded	Survey content	Usage
Enterprise 1	Aviation generator design and manufacture	90 min	25000 characters	Interviewed the director of sustainable development twice	Coding
Enterprise 2	Automobile R&D and manufacturing	50 min	8000 characters	Interviewed the supply chain technical manager once	Coding
Enterprise 3	Auto parts R&D and production	40 min	8000 characters	Interviewed EHS manager once	Coding
Enterprise 4	Medical product R&D and production	90 min	18000 characters	Interviewed EHS manager once	Coding
Enterprise 5	Passenger car R&D and manufacturing	90 min	22000 characters	Interviewed supplier development section chief once	Coding
Enterprise 6	Chip R&D and manufacturing	45 min	9000 characters	Interviewed the production manager once	Coding
Enterprise 7	Automobile R&D, production and sales	40 min	7000 characters	Interviewed the manager of supply chain management department once	Coding
Enterprise 8	Auto parts R&D and production	60 min	15000 characters	Interviewed EHS manager once	Coding
Enterprise 9	Drug R&D and manufacturing	100 min	26000 characters	Interviewed EHS manager and purchasing manager once	Testing
Enterprise 10	Decorative building materials production	60 min	10000 characters	Interviewed purchasing manager once	Testing
Enterprise 11	Diesel engine R&D and production	120 min	30000 characters	Interviewed purchasing manager and production manager once	Testing
Enterprise 12	Automotive sensor R&D and production	150 min	32000 characters	Interviewed general manager once, and interviewed purchasing manager once	Testing

in the supply chain of an enterprise, customers will boycott their products, which will also affect the reputation.

The Internal Factors

One of the main reasons why core companies are unwilling to be more active on sustainability issues is the lack of information, resources, and expertise in this area, leading to the poor ability of enterprises to achieve sustainable development (Zu and Kaynak, 2012; Bhakoo and Choi, 2013. Enterprise-level capabilities are a combination of various resources, such as material, human, and various corporate assets, including the "ability" of human resources (Eisenhardt and Martin, 2000). Gavronski et al. (2011) proposed that the cooperation between an enterprise and its supply chain partners embodies high-level capabilities. Over time, organizations face various changes and challenges from internal and external stakeholders, such as customers, suppliers, governments, competitors, etc. In this case, organizations must enhance capabilities and design strategies to cope with environmental changes (Freeman, 2010), which is consistent with the dynamic capability perspective (Teece et al., 1997). Enterprises must have the ability to use organizational processes to integrate, establish and re-allocate internal and external resources, design new value creation strategies to meet the sustainability requirements of stakeholders, reduce risks, and ensure their long-term performance (Teece et al., 1997). Resource availability also plays an important role in managing the sustainability in supply chain (Gong et al., 2019). The formation of social demand in the supply chain only depends on sufficient resources, but also on the ability of resource utilization (Mani et al., 2020). Compared with small and medium-sized enterprises, large enterprises can provide financial, human and technical resources to help their supply chain partners improve their sustainability performance (Vachon and Klassen, 2008; Wu et al., 2010). Large companies have more market force, so they are more influential among supply chain partners (Ayuso et al., 2013). In addition, Walters and James (2009) regard profitability and business efficiency as the driving force of core enterprises to promote and support supplier health and safety management.

Small and medium-sized enterprises are usually the suppliers of large enterprises, and more and more small and medium-sized suppliers are encouraged to take social responsibility and express these social responsibility requirements to their suppliers (Ayuso et al., 2013). However, sustainable supply chain management is challenging. Sub-suppliers may lack information and expertise and have weak relationships with core companies (Grimm et al., 2014; Wilhelm et al., 2016). Due to lack of resources and methods (Nawrocka et al., 2009), these small and medium-sized enterprises usually tend to communicate supply chain sustainability standards rather than implement control mechanisms (Touboulic and Walker, 2015). Although enterprises usually incorporate sustainability into their operations, they still don't know how to extend sustainability to their supply chain partners through sustainable supply chain management, and drive and influence this process (Gong et al., 2019). Studies have shown that the ability used in environmental practices can help meet social needs, that is, the experience gained by enterprises in environmental management can be applied to social activities in supply chains (Van Hoof and Thiell, 2014).

The existing research literature shows that: (1) the existing research literature on the mechanism of the various influencing factors on the work safety management behavior of the core enterprise in supply chain mostly focuses on investigating the direct impact of each independent explanatory variable on the sustainable behavior of the enterprise supply chain, but the different influence paths of various variables are rarely accurately explored. (2) The existing literature shows some driving factors for the sustainable management of the core enterprise supply chain, and it is expounded from external factors such as stakeholder pressure and internal factors such as corporate capabilities. There are correlations and crossovers among external factors. The pressure exerted by stakeholders, the transmission from pressure to behavior, and the driving force of other internal factors (such as corporate management awareness) on corporate behavior are rarely explored. (3) There is limited literature on work safety management behaviors in supply chain of core enterprises. Although many variable categories studied in the literature (such as green supply chain management behavior, supply chain sustainable management behavior, supply chain social responsibility management behavior, etc.) are related to supply chain work safety management behavior. However, the connotation of these variables is not completely consistent with the work safety management behavior in supply chain. Supply chain work safety management is unique and should be independent of supply chain sustainability management, and it is worthy of attention.

Based on the relevant research results at home and abroad, the author studies the core enterprise supply chain work safety management behavior. The key factors and influence paths of enterprise supply chain safety management behaviors are explored in order to provide the theory and experience for the government to formulate effective guiding policies to promote the core enterprises to adopt supply chain work safety management behavior.

RESEARCH METHODS AND DATA SOURCES

At present, there is no mature variable category, measurement scale and theoretical hypothesis for core enterprise supply chain safety management behavior. In addition, according to field investigation, many enterprises have different views on supply chain work safety management behaviors, so it may not be effective to directly design undifferentiated structured questionnaires to conduct a large sample quantitative research on the public. Therefore, unstructured questionnaires (open-ended questionnaires) are used to interview relevant principals of representative core enterprises to collect first-hand information, and qualitative research is used to explore the supply chain safety management behavior of core enterprises more effectively. The interview subjects who may guide the development of the theory are selected through the theoretical sampling. Since qualitative research requires interviewees to understand the work safety management in supply chain, a core company in a supply chain with many suppliers is selected to conduct in-depth interviews on its purchasing managers, supply chain sustainability managers, EHS (environment, health and safety) managers, production managers or manager of supply chain technology department. All interviewees have worked in positions related to work safety management in supply chain for more than 5 years and are familiar with the process and system of cooperation between the enterprise and suppliers. Determine the number of samples based on theoretical saturation, that is, when new data do not produce new concepts and categories, the theoretical sampling process stops. Finally, 16 middle and senior managers from 12 core enterprises in China were interviewed. During the interview, after asking for permission, we recorded the content (the total recording length was 935 min). After the interview, we sorted out the recording materials (the interview transcript was 210,000 characters in total) and completed the interview records and memos. **Table 1** shows the basic information of in-depth interview. The interview records of 8 enterprises were randomly selected for coding analysis and model construction, and theoretical saturation test was conducted for the interview records of the other 4 enterprises.

Grounded Theory, the exploratory research technology, is mainly adopted in this study. Through three steps of open coding, axial coding and selective coding for text data, the theory of core enterprise supply chain work safety management behavior and its driving factors are constructed. The data are continuously compared to refine and revise theories until theoretical saturation is realized (that is, newly acquired data no longer contribute to theoretical construction). The grounded theory research process of this study is shown in **Figure 1**.

CATEGORY REFINEMENT AND MODEL CONSTRUCTION

Open Coding

Open coding is to code, label, and log the original interview data word by word to generate initial concepts and discover conceptual categories from the original data. In order to reduce the bias, opinion or influence of researchers, the respondents' own words are used as labels to extract initial concepts. In this way, more than 600 original statements and corresponding initial concepts are obtained. Since there are many initial concepts and there is overlap among them, and category is the reclassification and combination of concepts, the initial concepts obtained are further categorized. When they are categorized, the initial concepts with low repetition frequency (less than 3 times) are eliminated, and the initial concepts with repetition frequency of more than 3 times are selected. In addition, individual inconsistent and irrelevant initial concepts that have nothing to do with the subject are eliminated. **Table 2** shows the initial concepts and several categories obtained. In order to save space, three original data sentences and corresponding initial concepts are selected for each category.

Axial Coding

The purpose of axial coding is to discover the logical relationships among categories, and to develop the main category and

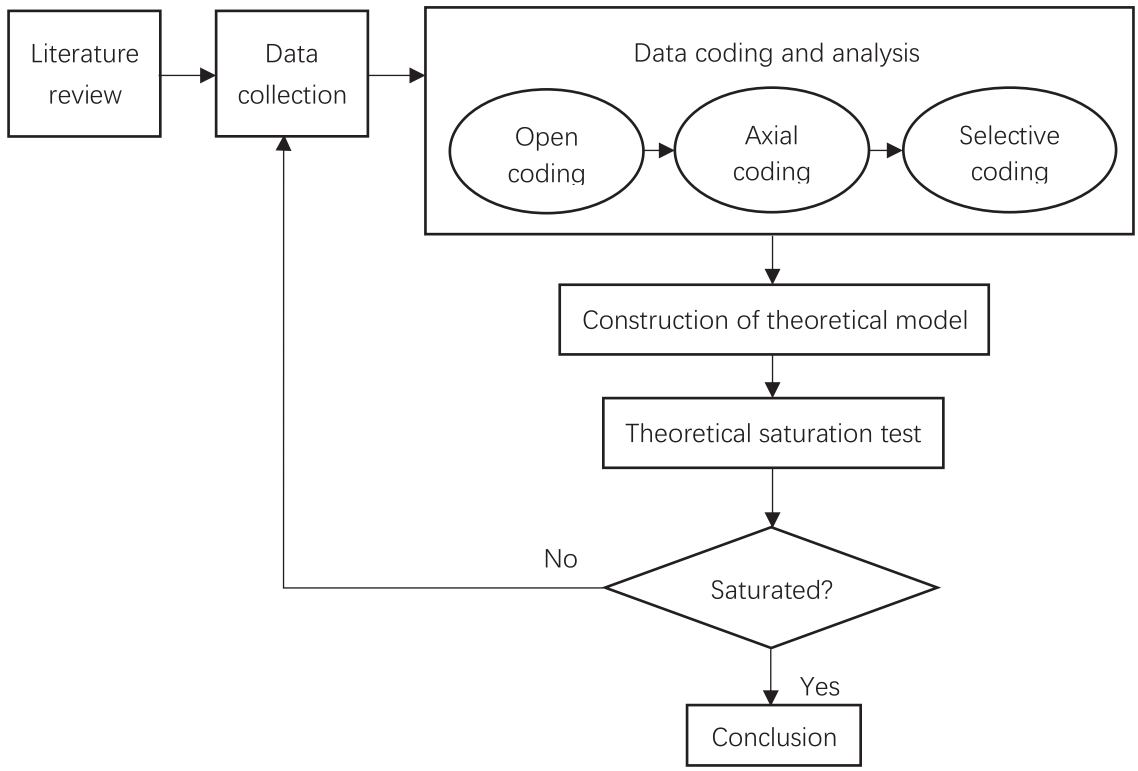

FIGURE 1 | Research process of grounded theory.

the corresponding sub-categories. According to the conceptual and logical relationship between different categories, they are classified into four main categories. Based on the relationship among different categories in concept level and logical level, four main categories are concluded. **Table 3** shows the main categories and their corresponding open coding categories.

Selective Coding

Selective coding is to dig out the connection among the main categories, and describe behavioral phenomenon and contextual conditions in a "story line" manner. After the "story line" is finished, a new substantive theoretical framework can be developed. The typical relationship structure of main categories is shown in **Table 4**.

"The driving factors and driving mechanism of the core enterprise supply chain work safety management behavior" is defined as the core category. The "story line" on the core category can be summarized as: institutional pressure, behavioral awareness, and behavioral capability have a significant impact on the main category of core enterprise supply chain work safety management behavior; institutional pressure is an external driving factor, and behavioral awareness and behavioral capability are internal driving factors; on the one hand, institutional pressure directly affects management behavior, on the other hand, it indirectly affects management behavior through behavioral awareness and behavioral capability; behavioral awareness and behavioral capability directly affect management behavior; behavioral awareness and behavioral capability can adjust the connection between pressure and management behavior. Based on the "story line," the driving mechanism model of the core enterprise supply chain work safety management behavior is constructed and developed, as shown in **Figure 2**.

Theoretical Saturation Test

The other 1/3 of the interview records are applied for the theoretical saturation test. The results show that the categories in the model have been developed completely. For the three main categories (institutional pressure, behavioral awareness, and behavioral capability) affecting the supply chain work safety management behavior of the core enterprise, there are no new important categories and relationships. No new constituent factors are found in the four main categories, including management behavior. Hence, the model is theoretically saturated.

EXPLANATION OF THE DRIVING MECHANISM MODEL

Through the previous analysis, it is found that the "external cause-internal cause-behavior model" can effectively explain the mechanism of the supply chain work safety management behavior of core enterprises. Specifically, the power elements of the supply chain work safety management

TABLE 2 | Open coding results.

Category	Source material	Initial concept
Regulatory pressure	"Chapter 7 of the "Medical equipment production quality management specification" has clear requirements for procurement, for example, when we purchase, screening supplier, supplier audit, and supplier control are clarified."	Policy document requirements
	"State Drug Administration of the people's Republic of China monitors us and audits our work, and it checks our key suppliers."	Government Regulation
	"The concept of supply chain safety appeared for the second time around 2017, led by the Ministry of Industry and Information Technology of the People's Republic of China, and it was called "Green Supply Chain."	Idea transmission
Normative pressure	"Suppliers must first be able to comply with safety requirements. If something happens and it is reported by the media, they will say our company did it on purpose because the cost is cheaper."	Media attention
	"To do business in this industry, one should comply with the industry's regulations. This is an industry with higher barriers.	Industry specification
	"For the case of Apple, the toxic n-hexane was used in Apple's supplier, which caused great negative social effects on Apple, as well as on the supplier."	Social pressure
Cognitive pressure	"In the industry, my peers or my customers have already applied these supplier safety management specifications."	Partner behavior
	"This is driven by the customers."	Customer demand
	"Supplier safety management is conducted to reduce costs and make us more competitive."	Competitive pressure
Responsibility sense	"We should co-exist and develop with suppliers, instead of producing by ourselves. Therefore, there is a high demand for supply chain sustainability."	Concept of supply chain sustainability
	"At present, the transmission to suppliers is mainly based on the enterprise's sense of responsibility and territorial awareness."	Supply chain social responsibility
	"Generally, in large companies, the top-level design is pushed down with advanced vision, such as the US headquarters."	Incorporated into the top-level design
Problem cognition	"In the automotive industry, once a supplier in supply chain is in trouble, our production and delivery will be affected."	Affecting product delivery
	"So, supplier safety is as important as product quality, and their weight is very important. If the supplier is not safe, it will affect the product quality."	Affecting product quality
	"For the medical industry, the cost of *ex post* control is (very large), and should I recall it? Should I suspend business for rectification after I was audited by various drug administrations and a finding was made? It is impossible. Therefore, most of supervision and policies are controlled in advance."	Problem severity perception
Behavioral effect perception	"The role and weight of the enterprise in the closed loop of supply chain determines whether an enterprise can dominate or play role in the supply chain."	Behavioral influence
	"I need to gain enough more voice in this industry, then I will release this information to my customers and suppliers for a virtuous circle. It makes me achieve a better position in the supply chain, so I can get goods with lower price."	Behavior enhances industry status
	"The common growth and assistance for suppliers is to reduce costs and increase efficiency, in fact, for economic benefits."	Economic value
Safety management strength	"When a company wants to conduct safety, in fact, it needs to develop a well understanding of safety, so that it can express a clearer and definite concept of safety to its industrial chain."	Management knowledge
	"How do we keep up with the requirements of this regulation, and how do we find changes in regulations, and how do we pass these changes on to suppliers? The second is how to make the supplier know its importance."	Ability to communicate safety specifications
	"For work safety problem, we use examples from our language to illustrate."	Ability to express safety requirements
Safety coordination capability	"Emphasis on compliance with the law is a bit of significance, and they will be calmer to do things."	Ability to coordinate conflict
	"How to help him and how to save the money. Conduct a return on investment calculation with the investor, and then we find a third-party financial company."	Ability to utilize third-party service resources
	"Most of the money is still in the return on investment. You make some savings, but everybody can earn profit."	Ability to share revenue
Safety evaluation	"We will regularly conduct on-site audits on suppliers and carry out some specific work."	Regular audit
	"The supplier's audit record, supplier's evaluation report, and production record must be handwritten."	Performance evaluation
	"If we find that there are major risks in suppliers, first, it is fined; second, reduce order allocation; third, if it is not improved, we may give him a red item in the annual audit, and may suspend its new project development."	Punishment
Safety cooperation	"There was mechanical crushing of suppliers that almost killed workers. In this case, we will provide technical assistance to suppliers."	Technical guidance
	"If some small suppliers are met with difficulties, Korean or Japanese companies will provide financial support."	Financial assistance
	"The suppliers may have poor performance in work safety, and we will send our work safety administrator to provide training."	Management guidance

The words in parentheses at the end of each sentence represent the initial concept obtained by encoding the original sentence.

TABLE 3 | The main categories formed by the axial coding.

Main categories	Corresponding categories	Relationship connotation
Institutional pressure	Regulatory pressure	Requirements from laws and regulations, government supervision and industry standards will affect the institutional pressure of core enterprises to implement supply chain safety management
	Normative pressure	The supervision and attention from the public, the media and the community will affect the institutional pressure of core enterprises to implement supply chain work safety management
	Cognitive pressure	The practices of partners, the behaviors of competitors, and the effects of competitors' management behaviors will affect the institutional pressure of core companies to implement supply chain safety management
Behavioral awareness	Responsibility sense	Whether the enterprise has a sense of social responsibility in the supply chain, the sustainable development of the supply chain, the sense of social responsibility, the support of senior management, the enterprise's attention on supply chain safety, and whether it is incorporated in the top-level design of the company's supply chain management will affect the behavioral awareness of core enterprise's implementation of supply chain work safety management
	Problem cognition	The accidents of supply chain work safety accidents affect the enterprise's product delivery, product quality, and brand reputation. Awareness of the seriousness of these problems will affect the core enterprises' awareness of the behavior of supply chain work safety management
	Behavioral effect cognition	The influence of enterprises adopting supply chain work safety management behaviors; customer recognition, media public recognition, and government recognition brought by management behavior; the change of management behavior on the enterprise's industry status affects the behavioral awareness of work safety management in the supply chain of core companies
Behavioral capability	Safety management strength	The understanding of knowledge of enterprise on work safety management and the ability to understand work safety regulations and express safety requirements and communicate specifications to suppliers affect the behavioral capability of core enterprise supply chain work safety management
	Safety coordination capability	The ability to coordinate conflicts when cooperating with upstream and downstream enterprises in the supply chain, and the ability to share safety risks and benefits with upstream and downstream enterprises affect the core enterprise's ability to conduct work safety management in supply chain
Management behavior	Safety evaluation	Formulating supplier safety supervision procedures, evaluating the supplier work safety performance, and providing rewards and punishments based on the evaluation results constitutes the core enterprise supply chain work safety management behavior
	Safety cooperation	The enterprise assisting suppliers in obtaining work safety certification, providing suppliers with work safety technical support, funding channels, and management guidance form the core enterprise supply chain work safety management behavior

TABLE 4 | Typical relationship structure of the main categories.

Typical relationship structure	The connotation of relationship structure
pressure → behavior	Institutional pressure is the external driving factor of the core enterprise supply chain work safety management behavior, and it can directly affect the core enterprise supply chain work safety management behavior
awareness → behavior	Behavioral awareness is the internal driving factor of the core enterprise supply chain work safety management behavior, and it directly affects the core enterprise work safety management behavior in supply chain
capability → behavior	Behavioral capability is the internal driving factor of the core enterprise supply chain work safety management behavior, and it directly affects the supply chain work safety management behavior of core enterprises
pressure → awareness → behavior	Institutional pressure affects management behavior by influencing the behavioral awareness of supply chain work safety management of core enterprises
pressure → capability → behavior	Institutional pressure affects management behaviors by influencing the core enterprise's supply chain work safety management ability
awareness pressure $\overset{\downarrow}{-}$ behavior	As an internal condition, behavioral capability affects the relationship intensity and direction between institutional pressure and management behavior
capability pressure $\overset{\downarrow}{-}$ behavior	As an internal condition, behavioral capability affects the relationship intensity and direction between behavioral awareness and managerial behavior

behavior of the core enterprises can be summarized into three main categories: institutional pressure, behavioral awareness and behavioral capability, which basically follow the general dynamic structure law of the development of things. However, their mechanism on the supply chain work safety management behavior of the core enterprises (that is, the way and path they affect the management behavior) is not completely consistent. The details are explained below.

The Direct Effect of Institutional Pressure

Institutional pressure (determined by the regulatory pressure, normative pressure, and cognitive pressure) is the external environmental factor of the enterprise that generates the motivation for work safety management in the supply chain. On the one hand, institutional pressure directly affects the supply chain work safety management behavior of the core enterprises. On the other hand, it also affects management behavior by acting on behavioral awareness and behavioral capability, respectively.

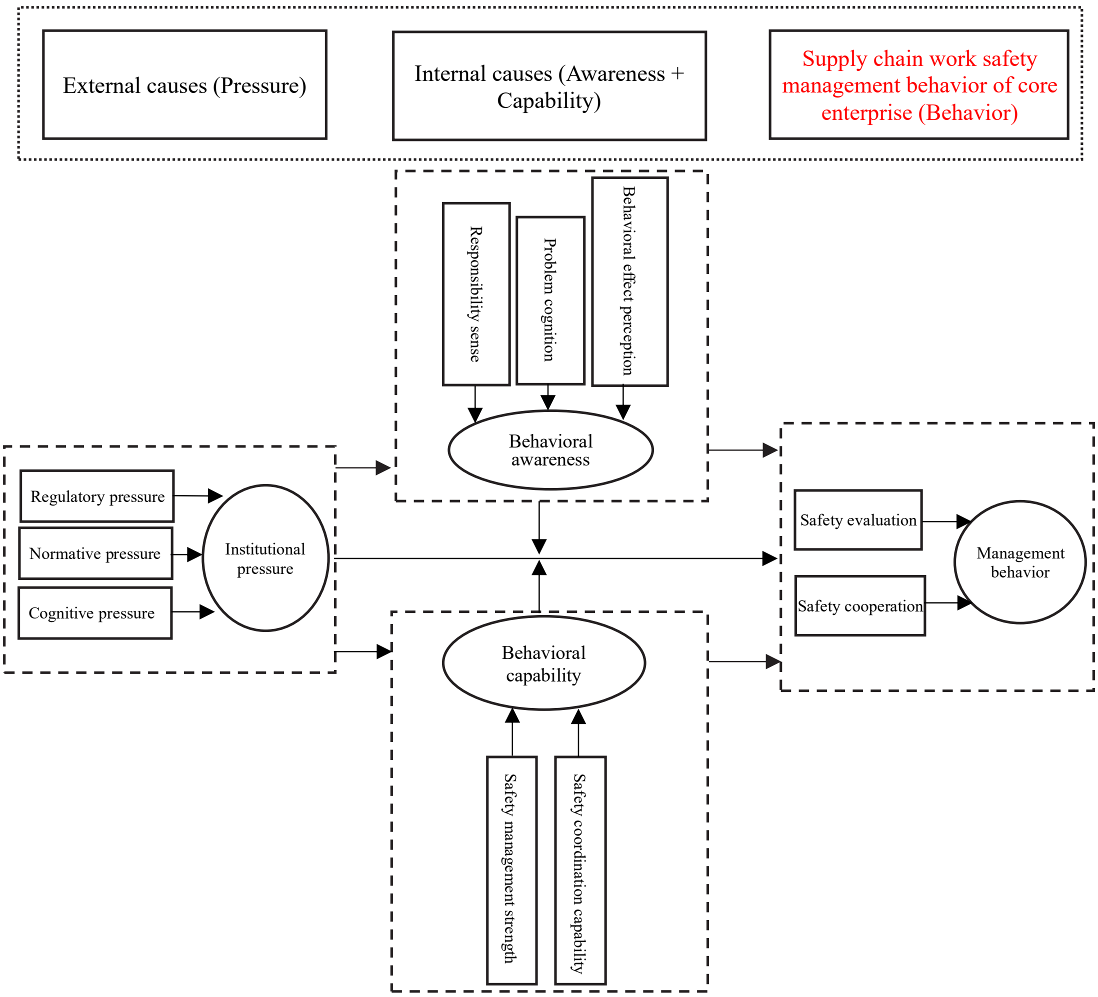

FIGURE 2 | Driving mechanism model.

It is the strengthening power for enterprises to conduct supply chain work safety management behavior. The source and intensity of institutional pressure will affect the positive relationship between pressure and behavior. (1) The source of institutional pressure will affect the positive relationship between pressure and behavior. When the pressure comes more from the government guidance, the management standards set by industry associations, the assistance of non-governmental organizations, and the excellent practices of partners, such source pressure will have a more significant positive effect on management behavior than pure moral preaching. For example, one manager mentioned "morality, I am very disgusted by such words. Why when we talk about work safety management in the supply chain, the enterprise social responsibility comes in? Enterprise social responsibility is all empty talk." (2) The intensity of institutional pressure will affect the positive relationship between pressure and behavior. When the institutional pressure is weak, the core enterprises hardly adopt the work safety management behavior in supply chain. At present, there are no relevant laws and regulations in China that clearly state that enterprises should be responsible for the work safety of their suppliers, so some enterprises do not pay attention to the work safety management in supply chain. It can be found from some of the views of the interviewees. For example, "The government has no requirements, and there is no requirement for safety management in supply chain. It focuses on quality management and quality assurance." It can be seen that when the institutional pressure reaches a certain critical point, as the institutional pressure increases, the motivation for enterprises to adopt supply chain work safety management behaviors is significantly enhanced. In addition to the source and intensity of institutional pressure, the way in which it acts will also affect its positive effect on management behavior. This will be explained in detail below.

The Mediating Role of Internal Motivations

Most previous studies focused on the direct impact of external factors such as institutional factors or stakeholder pressure on supply chain management behavior. Through in-depth interviews and qualitative research in this paper, it is found that the significance of internal factors in enterprise on the supply chain work safety management behavior of the core enterprises cannot be ignored. The path of external factors on management behavior is explored. The internal motivations of the supply chain work safety management behavior of enterprises include behavioral awareness (the subjective initiative factor of the enterprise) and the behavioral capability (the objective regularity of the enterprise). Behavioral awareness is composed of responsibility sense, problem cognition and behavioral effect perception. The behavioral capability is composed of safety management strength and safety coordination capability. On the one hand, the internal motivation plays an intermediary role in the relationship between institutional pressure and management behavior, that is, institutional pressure affects management behavior indirectly through the internal motivation. Specifically, institutional pressure promotes the management behavior of the enterprise by enhancing the awareness or capability of the supply chain work safety management behavior. For example, on the one hand, pressure from the government or society can stimulate enterprises to meet external legal requirements. On the other hand, the guidance and assistance from the government or society can enhance the internal and external strength of enterprises to participate in the work safety management in supply chain. First, the production and development of an enterprise requires its interaction with stakeholders, and gaining the recognition of stakeholders is the prerequisite for interaction. The external environment exerts institutional pressure on enterprises. In order to gain recognition, enterprises need to meet the demands of stakeholders. Therefore, the awareness of work safety management behavior in supply chain and management willingness are generated. Second, the core enterprises supply chain work safety management capability is a dynamic capability, in addition to the enterprise capabilities and foundation, its cultivation and promotion requires external resources and social capital. Obtaining resources across organizational boundaries can expand the corporate knowledge pool and support the cultivation of corporate behavioral capabilities through resource supply. The external institutional environment can provide enterprises with a resource basis for work safety management in supply chain, and empower them. Enterprises with strong behavioral capabilities can seize opportunities through the resource integration to adopt supply chain work safety management behaviors. The external institutional pressure influences management behavior indirectly by cultivating the behavioral awareness and behavioral capability of core enterprises. Therefore, behavioral awareness and behavioral capability, as effective intermediary between institutional pressure and management behavior, have a pulling effect on the supply chain work safety management behavior of enterprises.

The Moderating Effect of Internal Motivation

On the other hand, internal motivations act by influencing the relationship strength and direction between institutional pressure and management behavior, so they are moderating variables. The moderating effect of behavioral awareness is affected by the source and intensity of the awareness. When the behavioral awareness is strong or comes from the factors that affect the vital interests of the enterprise, such as brand maintenance, product quality assurance and supply chain risk control, that is, when enterprises perceive that it is profitable to implement supply chain work safety management, the moderating effect of behavior awareness is more significant. For example, some interviewees said, "So it is conducted based on interests. Since the enterprise is profitable and can grow rapidly, and it can reflect social responsibility, why not do it"? Conversely, when behavioral awareness comes from the ethical requirements of social responsibility and taking management behaviors does not benefit the actual operation of the enterprise, the moderating effect of behavior awareness is weak. For example, some managers said, "in our industry, there is little demand." "In fact, I think this kind of risk is acceptable, and there is no need for supplier work safety management."

The moderating effect of behavioral capability is affected by the characteristics of capability, which include strength and structure. When an enterprise has strong behavioral capabilities or comprehensive capabilities, that is, the enterprise not only has a high level of work safety management, but also has the corresponding supply chain safety management capabilities, its moderating effect is more significant; conversely, the moderating effect of behavioral capability is small. For example, one interviewee said, "The work safety management capability in supply chain depends on an enterprise's background, foundation and people inside. It is a comprehensive evaluation. The more successful of the enterprise is, the talents it chooses should be professionals with certain qualities and planning capabilities."

When the institutional pressure is weak and the moderating effect of internal motivations is relatively strong, the supply chain work safety management behavior of core enterprises is more affected by internal motivations. For example, one manager said, "If the government's financial incentive is only a one-time policy, it is only the icing on the cake for the enterprise. Promoting enterprises to implement supply chain safety management requires the comprehensive strength of enterprises themselves." Therefore, when the institutional pressure is weak, enterprises do not take management actions because of low input and output. Conversely, when the institutional pressure is high, the moderating effect of internal motivations is relatively weak.

RESULTS AND DISCUSSION

Results

In the current global economy, enterprises are gradually relying on outsourcing some business activities and processes, and enterprises and their suppliers are in a specific network, that is, a supply chain network. As the center of the supply chain, the core enterprises regulate and govern the supply chain, maintain direct contact with customers, and design and provide products and service (Seuring and Müller, 2008). The fulfillment of enterprise functions depends on the level of supply chain. This trend of outsourcing and the increasing importance of supply chain influence the working conditions, health and safety of supplier workers. Therefore, this paper studies the internal and external factors that influence core enterprises to adopt the behavior of supply chain work safety management to put forward policy suggestions for the government to guide core enterprises to participate in supply chain work safety governance, improve the work safety level of small and medium-sized suppliers and the sustainable development of the whole supply chain.

This study shows that institutional pressure, behavioral awareness and behavioral capability have a significant impact on the core enterprise supply chain work safety management behavior. Among them, institutional pressure is the external motivation for enterprises to adopt management behavior, and behavioral awareness and behavioral capability are the internal motivations. On this basis, this paper explores and constructs the mechanism model of the above three main categories on enterprise supply chain work safety management behavior. The main findings include: (1) the supply chain work safety management behavior of the core enterprises is not only affected by external institutional pressure, but also by the internal behavioral awareness and behavioral capability. (2) The formation mechanism and constituent factors of institutional pressure, behavioral awareness, behavioral capability, and supply chain work safety management behavior are explored. For example, the constituent factors of behavioral awareness include responsibility sense, problem cognition and behavioral effect perception; the constituent factors of behavioral capability include safety management strength and safety coordination capability. The sub-categories of problem cognition, behavioral effect perception and behavioral capability have not been emphasized and categorized in previous literature. (3) The influence mechanism of institutional pressure on behavior and the mediation and moderation of internal motivations on the relationship between pressure and behavior, especially the source and intensity of institutional pressure affect the positive relationship between pressure and behavior; the institutional pressure affects the enterprise management behavior through behavioral awareness or behavioral capability; the moderating effect of behavioral awareness is affected by the source and intensity of awareness; the moderating effect of behavioral capability is affected by the strength and structure of the capability; the moderating effect of internal motivations and institutional pressure are in a trade-off relationship. These findings inspire for the government guidance measures proposed in this paper, that is, simply increasing pressure cannot significantly drives enterprises to participate in work safety management in supply chain, and it is necessary to pay attention to the source and composition of external institutional pressure, and clarify whether external pressure promotes behavioral awareness and behavioral capability within the enterprise.

Contributions

Theoretical Contributions

Core enterprises to adopt effective work safety management behaviors in supply chain is conducive to reduce supply chain safety risks, and is a beneficial supplement to the government safety supervision. That is, the market mechanism is used to improve the work safety level of small and medium-sized suppliers. However, existing studies lack an in-depth exploration of the work safety management behaviors in supply chain of core enterprises. At the same time, existing studies on the drivers of supply chain sustainability management integrate work safety into the sustainability management, lacking consideration of the uniqueness of work safety management in supply chain. Hence, through an in-depth analysis of typical enterprises' supply chain work safety management practices, the author proposes a model of core enterprises' supply chain work safety management behavior driving mechanism around the uniqueness of supply chain work safety management, and clarifies that core enterprises' adoption of supply chain work safety management behavior is influenced by external institutional pressure, enterprise behavior awareness and enterprise specific behavior capability. Unlike existing studies focusing on examining the direct impact of each independent variable (considering external stakeholder pressure factors or enterprises' internal capacity factors) on enterprises' supply chain safety sustainability behavior, the author specially studies the supply chain safety management independently of sustainable supply chain management. Second, it is found that internal factors (including supply chain safety responsibility awareness, perception of supply chain safety issues, perception of effectiveness of safety management behaviors in supply chain, corporate safety management strength and supply chain safety coordination capability) are important driving forces of work safety management behaviors in supply chain that cannot be ignored. Finally, the author does not stop at listing the internal and external drivers that influence the adoption of supply chain safety management behaviors by core enterprises, but further focuses on the transmission mechanisms of internal and external factors on enterprises' work safety management behaviors in supply chain. Safety management is a unique and important issue that is fundamental to the development of corporate production and it should be emphasized in supply chain management of core companies. This study can draw attention to the uniqueness of the work safety management in the study of behavior-driven mechanisms of supply chain sustainability management.

Practical Contributions

The participation of core enterprises in supply chain work safety management is an important complement to government work safety controls. Although existing research on supply chain sustainability management gives some ideas and measures to drive enterprises to adopt sustainable behaviors, these measures lack the relevance to address the lack of motivation of enterprises to adopt work safety management behaviors in supply chain. The model of core enterprises' supply chain work safety management behavior driving mechanism in this paper can be used to provide targeted policy ideas and implementation paths for the government to develop effective control policies to guide core enterprises to adopt effective supply chain work safety management behaviors. The details are described below.

(1) Create an institutional environment to enhance behavioral awareness:

Firstly, motivate the supply chain sustainable development concepts and supply chain social responsibility of core enterprises through a variety of methods. Some core enterprises lack the concept of sustainable development in supply chain, and fail to realize that competition among enterprises has evolved into competition among supply chains. Therefore, the government and society should spread management concepts, create an environment of public opinion, stimulate the management awareness of core enterprises, guide more enterprises to participate in supply chain work safety management, and create a safe and healthy supply chain network. Secondly, improve the awareness of work safety management in supply chain. Some core enterprise managers lack awareness of the work safety in supply chain. Lastly, improve core enterprises' perception of the effect of supply chain work safety management behavior. Some core enterprises only regard supply chain work safety management as an extra cost expenditure, with fixed thoughts, and do not take the initiative to explore new management innovation mode to seek the economic value of supply chain work safety management. From the perspective of the profit-seeking nature of capital, the economic benefits of social responsibility behaviors are the internal driving force for enterprises to fulfill their social responsibilities. From the perspective of strategic social responsibility thinking, Porter and Kramer (2006) pointed out that competitive advantage is the result of the integration between the social responsibility strategy and the internal and external environment of enterprises (the government creates the environment). If enterprises take the initiative to incorporate social responsibility into their strategy, fulfilling social responsibility can become a source of opportunity, innovation and competitive advantage (Nawrocka et al., 2009). Strategic management of social responsibility can transform the undertaking of social responsibility from cost to enterprise resources and capability that can create value to form competitive advantage. On the one hand, the government can promote the influence of enterprises in the industry by advocating enterprises to participate in the formulation of industry norms. On the other hand, all sectors of society need to advocate enterprises to operate in a responsible and sustainable way, make positive contributions to the safe and healthy development of supply chain, and bring more opportunities for innovation, stronger partnership and more sustainable growth for enterprises themselves.

(2) Help companies improve their behavioral capabilities:

The way for sustainable development of the supply chain lies in improving management capabilities. While achieving its own sustainable development, it will drive the sound development of the entire supply chain, prompt upstream suppliers to further regulate their production behavior and production methods, and attract potential suppliers to actively achieve work safety. Standardizing supply chain work safety management requires not only sufficient resources but also the ability to use resources effectively (Mani et al., 2020). The quality level of suppliers is uneven, as is the core enterprises. In order to improve the behavioral capabilities of work safety management in supply chain, first, it is necessary to improve the safety management strength of core enterprise, including safety management knowledge, technical strength, and human resources. Only when an enterprise has its own safety management strength and a good safety performance can it spread safety concepts and management methods to the upstream and downstream in supply chain. Second, enhance the safety communication and coordination capabilities of core companies in the supply chain. Establish information exchange media and platforms, organize core enterprise supply chain security management exchange conferences, and encourage enterprises to exchange experiences and learn from each other's excellent management practices. When the core enterprise cooperates with the upstream and downstream in supply chain, learn how to coordinate the conflicts between the work safety requirements and the production and operation of the supplier enterprise, and how to share the safety risks and the safety benefits with the upstream and downstream enterprises.

Finally, interactive learning should be advocated. Enterprises in the supply chain network should learn from each other's excellent management experience. The government and all sectors of society should create an institutional environment. Through the stakeholder network, explore and publicize the management model, advocate interactive learning and set up industry benchmark, and enhance the management capability of core enterprises. The government and all sectors of society provide more resources and recruit more relevant parties, such as NGOs and work safety service agencies, to assist core enterprises in supply chain work safety management. The unified understanding and collective action of all supply chain members and the dialog and information sharing among supply chain members are conducive to forming consensus and synergy, maximizing the advantages of supply chain enterprises and jointly creating a safe and healthy supply chain.

Limitations and Future Work

The limitations and future work of this study are as follows. Since the supply chain work safety management behavior and its driving factors model are proposed based on the exploratory study, the reliability, validity and popularization have not been tested by large-sample statistics, in the future, it is necessary to conceptualize the variable categories involved in the model and develop a measurement scale, and a large-scale questionnaire survey can be used to test the exact relationship among the variables in the model. Furthermore, when the government and all walks of life are formulating policies and systems that guide more enterprises to participate in work safety management in supply chain, what is the mechanism and effect of a specific policy system for promoting the enterprise management behavior, and how to coordinate different policies to maximize the integration effect can be determined through setting up scenario experiments and simulation by using computer.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

QM provided the financial support and designed the manuscript. QZ and SL carried out the formal analysis. QZ and JZ wrote the original draft of the manuscript. QW performed the methodology. All authors contributed to the article and approved the submitted version.

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Informal Safety Communication of Construction Workers: Conceptualization and Scale Development and Validation

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Existing studies have highlighted the importance of informal safety communication among workers at construction sites. However, there is still a lack of empirically tested theoretical models with valid and reliable scales for describing and measuring construction workers' informal safety communication (CWISC). Accordingly, this study aimed to fill this need by developing an instrument to assess the communication performance of construction workers. Four stages of scale development were described: construct formation, item generation, factor extraction through the exploratory factor analysis (EFA) (n = 219), and scale assessment through the confirmatory factor analysis (CFA) (n = 156). Using questionnaire data drawn from construction workers in China, the CWISC was verified to be a three-dimensional construct including citizenship safety communication (CSC), self-needed safety communication (SSC), and participatory safety communication (PSC). The corresponding CWISC scale with 12 items was shown to have acceptable internal consistency reliability, as well as content, convergent, and discriminant validity. The CWISC scale could serve as an instrument to assess and identify the weaknesses in informal safety communication performance of construction workers. In turn, this information could help supervisors implement appropriate management practices to those workers to enhance workplace informal safety communication. Related studies taking a multidimensional CWISC into account were expected to be carried out.

Keywords: informal safety communication, scale development, intrinsic motivation, factor analysis, Chinese

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INTRODUCTION

Despite constant efforts for safety management over the past few decades, construction safety has not been improved as much as compared to other industries, it still witnesses a high rate of accidents (Zaira and Hadikusumo, 2017; Liang and Zhang, 2019). From the perspective of accident investigation, workers' unsafe behaviors were identified to be the primary and immediate cause of accidents considering that nearly 80% of on-site accidents were caused by unsafe human behaviors (Choi et al., 2017; Li et al., 2017; Zhang et al., 2019). Continued efforts to deepen understanding and decrease unsafe behaviors are still urgently needed.

Safety communication has been regarded as potential intervention for construction workers' unsafe behaviors (Cigularov et al., 2010). It is not just a process of exchanging safety information and knowledge at the workplace (Liao et al., 2014), but involves effects on workers' behaviors and their perceptions of safety (Shuen and Wahab, 2016). Safety communication was discussed in many studies for its significant potency in high-risk work environments (Zohar and Luria, 2003; Chan et al., 2016; Albert and Hallowell, 2017). From the perspective of information flow, safety communication can be carried out in three directions, upward, parallel, and downward (Yates and Orlikowski, 1992). Considering the role played by it in these situations, when detecting potential hazards and learning specific safety rules to adhere (Parker et al., 2001; Shuen and Wahab, 2016; Pandit et al., 2020), improving safety communication was suggested to be an essential measure in achieving fewer safety incidents on job sites (Vecchio-Sadus, 2007; Kines et al., 2010; Liao et al., 2014). Workers constitute the largest group on construction sites, and homogeneity of their identities reasonably increases the tendency of safety communication within crews (Turner et al., 2010; Allison and Kaminsky, 2017). Parallel safety communication, an action between subjects with the same position, was more likely to promote safety behaviors compared with leader–worker interactions (Zhou et al., 2008; Lingard et al., 2019). Given that the importance of leader–worker safety communication had been supported and highlighted in existing studies (Huang et al., 2018; Su et al., 2019), parallel safety communication between workers needs more attention.

The communication structure of a successful organization should include both formal and informal communication. Construction workers' informal safety communication (CWISC) was defined as safety-related information sharing through channels outside pre-established structures of an organization (Alsamadani et al., 2013). It is a personal activity held at work place with no arranged agenda, and takes the typical form as an impromptu safety conversation based on the current exposures that may be urgent and alarming (Tang et al., 2015). Specific dialog situations can be "A worker passes by another worker and reminds about a past hazardous event to avoid its reoccurrence," and "A worker asks another worker for advice on safety operation."

In contrast to formal safety communication preplanned at a fixed time as pre-construction safety trainings or toolbox talks (Rajendran et al., 2009; Hallowell, 2012), CWISC provides a more flexible channel, which is not limited by time and place, this preponderance contributes to convey safety information in a timely manner (Wu et al., 2017). When workers are caught in information ambiguity triggered by perceived risks in the process of operation, the action of seeking safety information from coworkers leads them to respond safely. The importance of CWISC has solicited attention from scholars in safety research areas, a few attempts were made to explore its characteristics and impacts on safety performance. According to a comparative research on the social network conducted by Alsamadani et al. (2013), the crew in which workers had numerous informal safety communication links presented a lower injury rate, and the closely linked crew showed an increased capacity to manage potential errors before they lead to an incident (Alsamadani et al., 2013). Further, using a modified questionnaire developed by Alsamadani et al. (2013), Allison and Kaminsky (2017) reported that workers in mixed-gender crews relied more heavily on informal communication for their safety information (Allison and Kaminsky, 2017).

Although the importance of CWISC in construction safety has been recognized, its core characteristics remained unclear, a lack of a well-designed (i.e., reliable and valid) measurement for assessing multidimensional CWISC was observed. In most existing studies, the existence of different channels (formal and informal) had been recognized, but they did not make a distinction when measuring it. For instance, Pandit et al. (2020) introduced both formal and informal safety communication among construction workers, but then all of these descriptions were reclassified into "safety communication" to be measured (Pandit et al., 2020). Limited studies focusing on measuring CWISC employed the method of social network analysis (SNA), which was argued to be inaccurate and error-prone (Fischbach et al., 2009), remained a vacancy in the measurement scale. In addition, practices of different types of CWISC were available in recent studies. Allison and Kaminsky (2017) described CWISC as "calling friends in another crew on how to handle a work problem" (Allison and Kaminsky, 2017), while Kaskutas et al. (2016) gave an example of it as "teaching dialog between experienced workers and other workers" (Kaskutas et al., 2016). The purpose for initiating the aforementioned safety communication was obviously different; nevertheless, the CWISC was generally treated as an unexpanded variable, and the categories and corresponding motivations of it remained unclear.

Being one of the exploratory studies on this issue, this article aimed to give a particular focus on identifying specific dimensions of CWISC and develop a well-designed instrument to describe and assess it. The research drew upon the insights of the safety communication literature, and engaged in a four-stage process to systematically explore and examine the measurement scale.

The Present Research

The goal of this research is to construct and validate an efficient measuring tool of CWISC capturing different dimensions. To reliably and accurately assess a theoretical construct, a systematic and rigorous process of development and validation should be followed (Farooq, 2016; Kim et al., 2021). A deductive–inductive approach with mixed methods (qualitative study and quantitative study) was applied to study the issue, by which both summative derived categories and those correlations randomly arisen from data may find their way into this study (Itzkovich, 2021). The approach was appropriate as there was little theory to guide notions about specific forms of CWISC (Yang et al., 2018).

For the development of a framework and the corresponding scale of CWISC, four activities were conducted with the help of voluntary construction workers in China; namely, construct formation, item generation and content validity assessment, exploratory factor analysis (EFA), and confirmatory factor analysis (CFA). The overall flow with relevant methods and

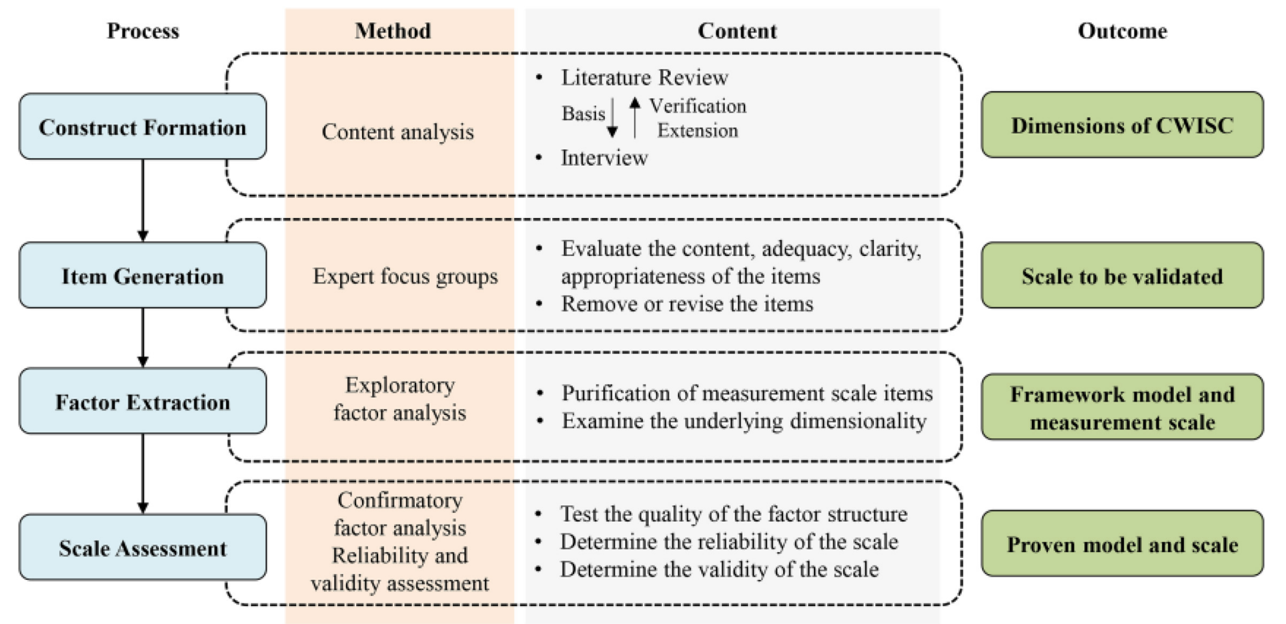

FIGURE 1 | Development process of the construction workers' informal safety communication (CWISC) scale.

specific contents embedded in the research was illustrated in **Figure 1**.

STUDY 1

Methods

Literature Review

Literature review, one of the qualitative research methods, was first applied to broaden insights into CWISC. Through a holistic summary, potential compositions of the construct can be used as a starting point to clarify the focus of the next stage. In this process, practices of safety communication and descriptions of related theories were collected from an open resource, then a series of pre-established categories were proposed (Hinkin, 1998; Yang et al., 2018).

Based on a systematic analysis of the potential terms, a three-level keyword structure, adaptively modified from Liang's search strategy (Liang and Shi, 2021), was adopted to cover diverse and large-scale search terms for comprehensively and reliably obtaining CWISC-related articles (as shown in **Table 1**). The context keywords defined the search context, which was limited to the construction industry; the topical keywords further narrowed the search scope; and the subject keywords limited the search subject to construction workers.

The Thomson Reuters's Web of Science (WoS) core collection database was selected because it is a source of standardized and high-quality academic publications. By restricting the literature type to article, a total of 78 candidate articles were obtained. To further eliminate the literature outside the target topic, abstracts were screened seriatim according to the criterion of minimizing information missing. After a careful screening process, a total of 37 CWISC-related articles were identified for the following literature review. The literature excluded involved the following themes: the development and application of emerging safety-related technology (BIM, virtual reality, wearable devices), safety communication in other industries, and safety communication between other participants (leaders and workers, management departments).

TABLE 1 | The used three-level keyword structure.

Search levels	Retrieval strategies
Context keywords	TS = ("construction industr*" or "construction work*" or "construction compan*" or "construction organization*" or "construction project*" or "building project*" or "construction site*" or "construction management" or "construction activit*" or "construction task*")
Topical keywords	TS = ("safe* communication*" or "safe* information*" or "communication* safe*" or "safe* voice*" or "safe* exchange*" or "safe* interact*" or "safe* discussion*" or "risk* communication*")
Subject keywords	TS = (employee* or worker* or coworker* or labo* or carpenter* or apprentice*)

"" Denotes the fuzzy search strategy that is used to capture the variation in terms. "TS" represents the topic research strategy where an article is included when required terms are identified in any positions of the title, abstract, and keywords.*

Semi-Structured Interviews

Participants

Recorded documents, participative observation, and interviews are all typical methods for obtaining data in qualitative research. However, workers' safety communications on construction sites are normally not recorded by the organization, and remote participative observation has limited access to the specific content of communication. Given this, semi-structured interviews were selected to excavate exact communication performances.

A number of semi-structured interviews to safety managers from several construction projects and workers within their jurisdiction were carried out in person, then a match between theoretical literature and practical conditions was checked to further bridge the gap. In total, 26 workers participated in the interview voluntarily from March 2021 to April 2021. To reduce self-reporting and recalling biases of workers, three safety managers and five supervisors, each with more than 5 years of safety management experience, were also invited to interview. Face-to-face and online interviews were selectively applied according to a comprehensive consideration of geographical accessibility and participants' wishes.

Procedure

Before interviews, CWISC was introduced to participants to give them a clear understanding about the concept, the action intensified the compatibility and validation of answers. Abide by the semi-structural interview syllabus, questions were executed in accordance with the following designed process (**Figure 2**). In addition to questions about workers' performances during safety communication, the reasons for carrying out or engaging in these activities were further explored. Open-ended questions were given to workers who have participated in safety communication. The significance of CWISC was affirmed by workers as the interactive process helped them understand safety rules better and behave in a safe manner.

For the interviews to safety managers and supervisors, they were asked for comments on workers' performances: "Are there private safety communication between workers on construction sites? Could you tell us any details of it?"

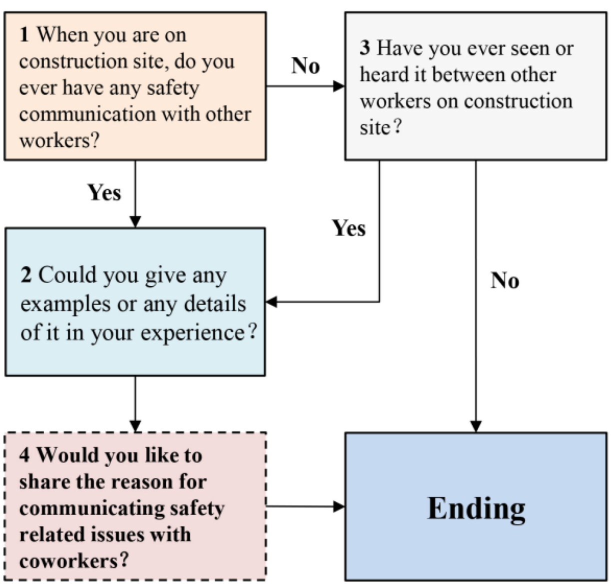

FIGURE 2 | The designed interview process.

Analysis

Transcription and analysis of interview recordings were performed by three researchers who mastered the content analysis method. After eliminating ambiguous and irrelevant responses, the following steps were adopted to obtain final classifications. First, keywords were extracted and marked from descriptive texts of safe communication performances and motivations. Then, these keywords were categorized into different themes and further matched with the initial types derived from the literature, this step continued until no matches emerged. Finally, the characteristics of the remaining unclassified themes were summarized and discussed to define new types.

Results

Preliminary Classification From a Literature Review

In terms of research paradigms and method applications, prior studies associated with workers' safety communication can broadly be split into two categories. The first embranchment took the communication social network as the primary research object, and comparative analyses were carried out to identify correlations between social network characteristics with specific safety performance [i.e., hazard recognition skill (Pandit et al., 2020) and safety climate (Lingard et al., 2019)]. The second embranchment presented empirical studies into safety climate and safety citizenship behaviors (SCB) within workgroups, aiming to reveal a causal mechanism with other organizational and individual indicators (Meng and Chan, 2020; Zhang et al., 2020). Within these studies, workers' safety communication behaviors were involved in subdimensions of the first-order construct. Surprisingly, empirical studies closely related to CWISC were relatively scarce.

Focusing on the collation of descriptions and measurements, valuable clues had emerged during the extraction process. Firstly, in terms of social network analyses, participants were commonly invited to fill in the names of workers with whom they exchange safety information, together with choosing options on different frequencies and modes, in which informal safety discussion and formal safety exchange (training, toolbox talking, and written communication) were, respectively, installed (Alsamadani et al., 2013; Kaskutas et al., 2016). Secondly, in the domain of safety climate, safety communication was considered to be one of the explanatory indicators of safety climate. Specific communication behaviors were adopted to directly measure the unidimensional safety climate or assigned to a subscale, sample items were "Coworkers remind each other to take precautions" (Zhang et al., 2020) and "Safety issues are openly discussed between my supervisor and my workgroup" (Beus et al., 2019). Further, similar items were applied to measure safety voice behavior, which was widely acknowledged as a subdimension of SCB. Safety voice was defined as an active behavior making constructive suggestions related to safety concerns (Yang et al., 2018). Typical descriptions were "I tell my colleague who is doing something unsafe to stop" and "I discuss new ways to improve safety with my colleagues" (Tucker et al., 2008).

Obviously, the aforementioned safety communication under different interests was endowed with diverse interpretations.

TABLE 2 | Preliminary classification of construction workers' informal safety communication (CWISC) from the literature.

CWISC classification	Described scenarios	References
Interpersonal helping	Instructional sessions with an experienced worker that may have a safety focus.	Kaskutas et al., 2016
	Calling friends on how to handle a work problem.	Allison and Kaminsky, 2017
	In this workgroup, coworkers remind each other to take precautions or work safely.	Gao et al., 2017; Zhang et al., 2020
	When my colleagues are in a dangerous situation, I will remind and help them in time.	Meng and Chan, 2020
	My co-workers are quick to point out unsafe conditions.	Beus et al., 2019
Safety discussion	Work-related discussions with co-workers.	Alsamadani et al., 2013; Ho, 2013
	Safety issues are openly discussed between my workgroup.	Beus et al., 2019
	'I've got this issue, do you guys have this issue?' 'Yeah, that's what I've had happen to me too, we resolve it by. . .'	Lingard et al., 2019
	I always discuss with my colleagues about improving safety and reducing the potential risks for the current works.	Tucker et al., 2008; Meng and Chan, 2020
	When you have safety related issue at work, you will discuss it with your colleague and request for assistance.	Chen et al., 2021

Due to the lack of a clear CWISC concept, the understanding of CWISC remained scattered and its subdimensions have not been fully expanded. Facing this challenge, two categories were aggregated grounded in analyses on the intention of communication. "Interpersonal helping," borrowing from Yang's definition, was used to describe the communication with helping intention (Yang et al., 2018), while "Safety discussion," drawing on the mentioned keyword, referred to the communication with an intention of sharing information. Typical statements were sorted as shown in **Table 2**.

Construct Formation

Given the greater amount of colloquial expressions, much time was spent on transcribing and summarizing the main ideas of workers. After removing ambiguous descriptions, such as communication actions with indeterminate time and place, the results of interviews came in the form of a 28,000-word interview record and 71 CWISC events. Keywords were summarized and marked to identify the initiator of the communication, the sender, and receiver of the information, the time, and purpose of the activity and the feeling of the communication, this process was conducted by taking the sentence as the unit of analysis. Considering that safety communication activities generally include basic elements, such as communicator, communication time, and safety information, a single keyword cannot be used as the basis for the identification and classification of safety communication activities, but a combination of keywords within a statement. Then, based on the keywords, 9 themes were generated and categorized into subdimensions of CWISC, the cumulative results of coding for CWISC were shown in **Table 3**, the results were verified, the proposed two types of CWISC were enriched, and further a third type was developed.

Because there was a lack of sufficient understanding on CWISC, the original name of aforementioned dimensions was drawn on keywords of existing studies. With the in-depth investigation of workers' performances and corresponding motivations, a rational perspective was expected to be followed so that they can be normatively and synchronously renamed. Intrinsic motivation, reported as a critical predictor of behaviors, was employed as a principle of naming. Finally, safety communication represented by "safety discussion" was categorized as participatory safety communication (PSC); citizenship safety communication (CSC) was used to summarize communication behaviors for the purpose of "interpersonal helping"; self-needed safety communication (SSC), a newly developed category, included communication behaviors of seeking self-protection.

Citizenship Safety Communication

In this study, the concept of CSC was first introduced for those altruism-based communication phenomena on construction sites. Similar to the definition of SCB, CSC refers to extra-role safety information exchange through informal channels. It focuses on improving coworkers' safety performances beneficial to coworkers and organization. Four detailed themes were gathered from interviews, they were "Informing coworkers of safety rules," "Reminding coworkers to notice safety," "Being asked about safety advice," and "Being reminded of safety matters by coworkers." Further, CSC accounted for 27 out of total 71 events, "Being asked about safety advice" was the most mentioned scope. Of the 27 reported CSC events, 11 were related to the active helping behaviors of communication initiators. In addition, workers reported some communication activities that were not originated by their own. In total, 10 workers claimed that they had been asked by fellow workers to confirm if the operation was safe as well as to explain the safety signs to coworkers.

Two characteristics of CSC were revealed through interviews. The first characteristic stresses its intrinsic altruistic motives of individuals, worrying about the potential injury of coworkers acting as a promoter for originating or participating in CSC. The second characteristic emphasizes that it is a discretionary positive act outside workers' responsibilities. Supervisors had made it clear that such helping behavior was encouraged but not prescribed, it would not be rewarded by the organization.

Self-Needed Safety Communication

The second type was SSC: help-seeking information exchange sought to ensure sponsor's own safety. During interviews, some workers pointed out the straightforward reason for taking SSC as they needed to keep themselves safe on worksites, which appeared to be an essential characteristic of SSC. Two themes under SSC were motivated by the worker's safety need; they were

TABLE 3 | The results of coding for CWISC.

Affiliation category	Themes	Concurrent keywords	Frequency	Samples of original statements from interviews
SSC	N1: Sending a self-protection signal	Information sender; active participation; self-safety; working time	6	N4 I am a scaffolder, once I was on the high scaffolding in the work, my coworker was going to carry out the work of downward adjustment of scaffolding, I hastened to signal my workers to stop and wait for me go down from the scaffolding.
	N2: Consulting to coworkers	Information receiver; active participation; self-safety; working time	9	N7 My parents and child depend on me, so I usually pay much attention on safety issues, I always consult the coworker or supervisor promptly when there is not clear on my work. N18 Once the supervisor asked me to take over the work of a worker, for safety purposes, I consulted with the worker in detail about the situation that had occurred in his previous operations.
CSC	N3: Informing coworkers of safety rules	Information sender; active participation; coworker's safety; explanation; working time	4	N03 When a new worker came to the crew, I took him to familiarize with the site and explained to him the safety rules to follow.
	N4: Reminding coworkers to notice safety	Information sender; active participation; coworker's safety; remind; working time	7	N15 Once when we were working, there was a safety hazard, I rushed to tell other workers to pay attention to.
				N25 A worker told me that he found his coworker had little safety awareness, he often reminded him at the construction site.
	N5: Being asked about safety advice	Information sender; passive participation; being asked; working time	10	N29 A worker found that the electricity line was slightly aging, he asked me if it could continue to use, he thought there would be no problem generally, I told him to immediately report to the supervisor and replace it.
	N6: Being reminded of safety matters by coworkers	Information receiver; passive participation; being concerned; working time	6	N19 While I was doing my work, a coworker told me to watch out for the high-tension line.
PSC	N7: Listening to others working experiences	Information receiver; discussion; rest time	5	N20 A worker told us a dangerous situation occurred previously which he had seen, he was scared after that, he reminded us to always be safe in our work.
	N8: Discussing with coworkers	Information exchanger; discussion; rest time	16	N12 Once a few of us workers discussed the meanings of a warning sign on site, the supervisor explained to us finally. N30 On several occasions, I saw workers chatting on site together, I learned through inquiries that they were sharing their experiences in safety operation.
	N9: Sharing during discussion	Information sender; discussion; rest time;	8	N6 I am willing to share my experiences when discussing safety issues with my coworkers.

"Sending a self-protection signal" and "Consulting to coworkers." SSC accounted for the least among the three communication behaviors, with only 15 events reported. Of the 15 reported SSC events, 9 were related to "Consulting to coworkers," others were "Sending a self-protection signal." These two themes represented different safety information flows. Behaviors of "Sending a self-protection signal" were accompanied by the sending of safety messages, whereas actions of "Consulting to coworkers" were expected to receive safety information.

Compared to the extra-role altruistic features of CSC, SSC is an intra-duty action that workers should perform to achieve their own safety. This important point of view emerged from the explanations of supervisors. They claimed that the organization had provided workers with the necessary safety training and protective equipment; in return, workers were given the responsibilities and obligations to operate in a safe manner. They should take positive actions to achieve safety goals, not only for the organization, but also for themselves.

Participatory Safety Communication

The third type, PSC, describes safety communication for the purpose of sharing and exchanging safety-related information. Specific themes were "Listening to others working experiences," "Discussing with coworkers," and "Sharing during discussion." There were totally 29 events associated with PSC, which was the most common form of CWISC.

Some distinguishing features of PSC were generated corresponding to the other two types of CWISC. PSC is first labeled by its analysis-oriented function compared to solution-oriented function of CSC and SSC. The focus of such an action is to share and exchange information with coworkers, it is about their own understanding of safety without an mixed intention for improving their own and their coworker's safety immediately. As workers described, they mostly carried out PSC during the rest time. The second characteristic stresses the dynamicity of the interactive process, in which the worker can act as both the sender and receiver of safety information.

TABLE 4 | A summary of the comparison of three subdimensions of CWISC.

	CSC	SSC	PSC
Motivation	Altruism-actuated	Safety needs	Sharing
Objective	Solve the problem	Solve the problem	Analyze the problem
Responsibilities attributes	Extra-role	Intra-duty	Extra-role
Occurrence time	Under construction	Under construction	Rest interval
Content	Operation-based	Operation-based	Extensive and random

Summative Comparison of Three Subdimensions

These three types of CWISC provided access to transmission and sharing of safety information between workers on construction sites. As communication is a process that requires the involvement of more than two individuals, it can be defined as different types according to motivations of participants. The following scenario is a common communication process, when worker A asks worker B for advice on how to operate in a safe manner, and worker B gives a detailed explanation. Defined from the motivation of A, he initiates SSC, whereas in terms of B, he participated in the CSC passively. A pertinent summarized comparison of the three subdimensions was presented in **Table 4** for legible understanding.

STUDY 2

Methods

Procedure

This study followed Evans's procedure of developing measurement items (Evans et al., 2007), the process of identifying scale items began by reviewing items used in previous measures of SCB, safety climate, and safety voice. Items that were applicable to the themes established earlier (N1–N9) were selected. Some items were included without a change, others were slightly modified to adapt to the construction background. Then additional items were written from interviews to fill in the themes that have not been populated. Items were designed to be general to apply across different trades. An example of a "general" item was "I can freely ask questions to my workmates if I have safety problems." An example of a "specific" item was "I can freely ask questions to my workmates when I do not know the right place to start taking down scaffolding." Further referring to the study of Zhang et al. (2020), items of communication perception were used in their study to measure safety communication between the supervisor and workers, sample items were "I feel that my supervisor encourages open communication about safety." and "I feel comfortable discussing safety issues with my supervisor." Then, in this study, supplementary items of communication perception (both forward and reverse items) were designed within each subdimension, these descriptions were derived from workers' viewpoints.

For the exploration of the extent to which the content domain of interest can be reflected by specific set items above, content validity of the initial CWISC scale was evaluated over two rounds. Both item- and scale-level content validity appraisal procedures were executed by a group of six experienced occupational safety experts (Polit and Beck, 2006; Man et al., 2019). The expert panel consisted of one woman and five men, of those, four worked in university, three worked in construction companies. In particular, one had a background in both university and construction company.

Analysis

After reviewing the items in first ground, experts were invited to rate each item on its relevance to the affiliated CWISC dimension with four grades (1—not relevant, 2—somewhat relevant, 3—quite relevant, and 4—highly relevant) (Polit and Beck, 2006). Concisely, the score represented its explanatory ability of the default dimension. The item with insufficient agreement on its relevance will be recorded. In second ground, a focus group discussion was implemented to revise items through supplementing, removing, and modifying. These two steps were repeated until all items passed the relevance assessment.

Content validity index (CVI) was the most widely reported approach in scale development studies (Zamanzadeh et al., 2015). According to Polit's and Beck (2006) recommendation, item-level CVI was calculated as dividing the number of experts giving a rating of either 3 or 4 on one item by the total number of experts, while scale-level CVI was determined by the average of CVI of all items in the scale (Polit and Beck, 2006).

Results

Based on the literature review and clues from interviews, the layout of total 22 communication scenarios was installed as the initial scale. These items were the description of representative behaviors, they were as general as possible to ensure that workers of various trades were likely to experience them in real-life work environment and they can easily understand the involved situations.

According to the abovementioned rationale and criteria, a content validity assessment was conducted. After eliminating four items that did not pass the assessment process, all 18 retained items had an item-level CVI of 1.0, which led to 1.0 of a scale-level CVI. On these grounds, items contained in the scale had fulfilled the criteria and appeared to be reasonable to measure CWISC. These 18 items displayed in **Table 5** were kept for the next stage. Items 1–6 were used to measure CSC, SSC was estimated by items 7–12, and the rest items were prepared for PSC.

STUDY 3

Methods

Participants

The data used in EFA were collected from questionnaire surveys. In the formal distribution from May 2021 to July 2021, questionnaires were dispensed to a total of 300 construction workers from high-rise residential building projects, several

TABLE 5 | Details of 18 items of CWISC.

Construct	Items	Statement	Themes	Source	Scale format
CSC	1	My workmates will accept my advice on safe operation.	N3, N4	Supplementary item from perception	An 5-point phrase completion scale ranging from 1 (indicating "strongly disagree" to 5 (indicating "strongly agree")
	2	I will tell my workmates how to operate safely when finding him working unsafely.	N3	Meng and Chan, 2020	
	3	I will tell him if I know when my workmates ask me about safety-related issues.	N5	From interview	
	4	My workmates often remind me to pay attention to safety and give me safety information.	N6	Lestari et al., 2020; Deng et al., 2020	
	5	Explaining safety problems to my workmate would delay my work time and schedule.	N3, N4	Supplementary item from perception	
	6	I will remind my workmate to pay attention to safety and give him safety information.	N4	Kincl et al., 2020	
SSC	7	When I am not sure about my operation, I will ask my workmates to make sure.	N1	Allison and Kaminsky, 2017	
	8	When I don't understand the safety signs on site, I will ask my workmates for an explanation.	N2	Kincl et al., 2020	
	9	In order to ensure my personal safety, I will confirm whether my behavior is safe with my workmates during the construction operation.	N2	From interview	
	10	My workmates is willing to answer my safety questions.	N2	Supplementary item from perception	
	11	I can freely ask questions to my workmates if I have safety problems.	N1	From interview	
	12	I find it troublesome to ask workmates for safety help and explanations.	N2	Supplementary item from perception	
PSC	13	I feel comfortable discussing safety issues with my workmates.	N8	Supplementary item from perception (Zhang et al., 2020)	
	14	I would like to share my safety operation experience with my workmates.	N9	Li et al., 2020	
	15	I often discuss safety issues with my workmates when taking a break on site.	N8	Deng et al., 2020	
	16	When my workmates discussing construction safety issues, I will actively participate.	N7	From interview	
	17	I am free to speak up when discussing safety issues with my workmates.	N9	Chen, 2017	
	18	Getting involved in safety discussions is a waste of my time.	N8	Supplementary item from perception	

cities in northern (Harbin and Shenyang), central (Jinan and Handan), and southern (Guiyang and Guangzhou) China were selected for investigation. Participations were voluntary and not required to provide any personal or identifiable information in the questionnaire.

Procedure

Before the formal investigation, a pilot test was performed for several selected workers. Questions were further simplified and rephrased to be much clear for workers with limited education. The final questionnaire consisted of two parts: measurement items and general demographic questions, including gender, age, years of work experience, education level, and trade types. Senior managers from the project emphasized the academic purpose of research to participants, and this support facilitated the development of investigation. Meanwhile, to ensure the quality of reply, workers who could not fully understand the statements completed it with the help of researchers. Finally, after removing incomplete replies as well as answers with high repetition, a total of 219 valid responses were used in the data analysis process (a response rate of 73%).

Data Analysis

Using Statistical Package for the Social Science (SPSS) 25, EFA was performed to render the number of latent variables based on commonalities and further inspect factor loadings of items. EFA is a statistical technique extensively applied in scale development to explore underlying dimensions of measurement items. Considering that there were a few references for multidimensional constructs of CWISC at the present stage, this study expects to maximize the use of survey data to explore objective laws. Principal component analysis (PCA), an adaptive exploratory approach for data processing, compression, and extraction, has been widely used in scale development studies. Through PCA, the cumulative explanation of extracted principal component (factor) to total variance can be maximized (Jolliffe and Cadima, 2016). This principle of factor extraction is consistent with the expectation of minimizing data losses in this study. Simultaneously, PCA is highly inclusive for data types, there is no need to make any assumptions about the prior distribution of evaluation data, e.g., normal distribution (Walker, 2010). Accordingly, the PCA method with an oblique rotation was preferred. Instead of commonly used orthogonal rotation, an oblique rotation is theoretically more accurate in the context of social science research in which correlations among factors are generally expected (Jian et al., 2014). On account of this, it is unreasonable to assume items to be completely uncorrelated to each other.

Sampling adequacy for EFA was assessed by the Kaiser–Meyer–Olkin (KMO) test and the value of p, with the criteria to be >0.50 and <0.01, respectively (Zhou et al., 2021). Equally, items with factor loading < 0.5 and loaded on the factors other than its design will be dropped out of scale. The accumulated variance explanation by extracted factors was expected to exceed 60% while Cronbach's alpha should be more than 0.70.

Results

Descriptive Analyses

According to the statistical analysis on valid respondents, respondents were mostly men (97.26%) due to the men-dominant workforce in the Chinese construction industry. Other demographic information was shown in **Figure 3**. The majority of

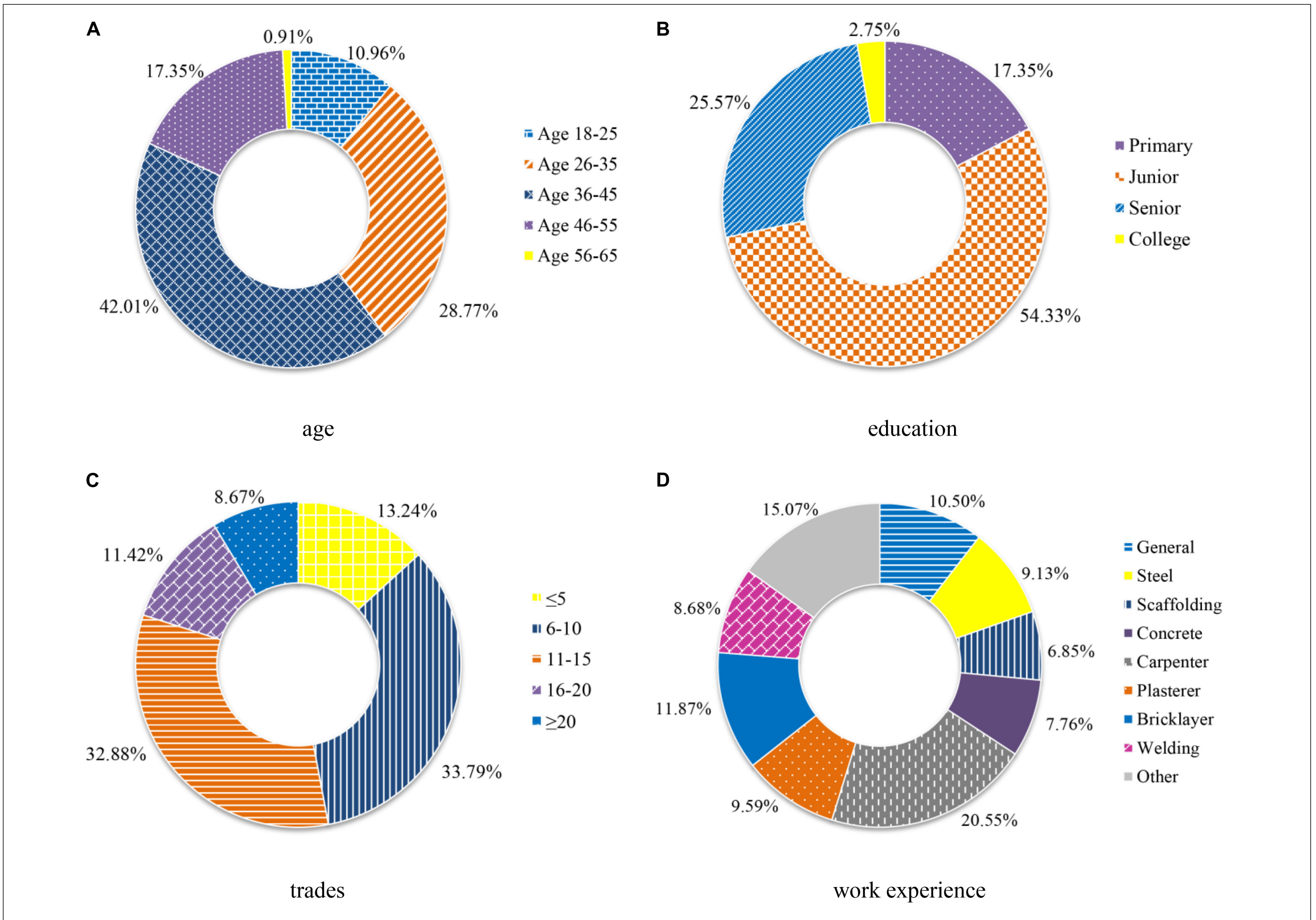

FIGURE 3 | Demographic profiles of workers participated in the exploratory factor analysis (EFA) in terms of **(A)** age, **(B)** education, **(C)** trades, and **(D)** work experience.

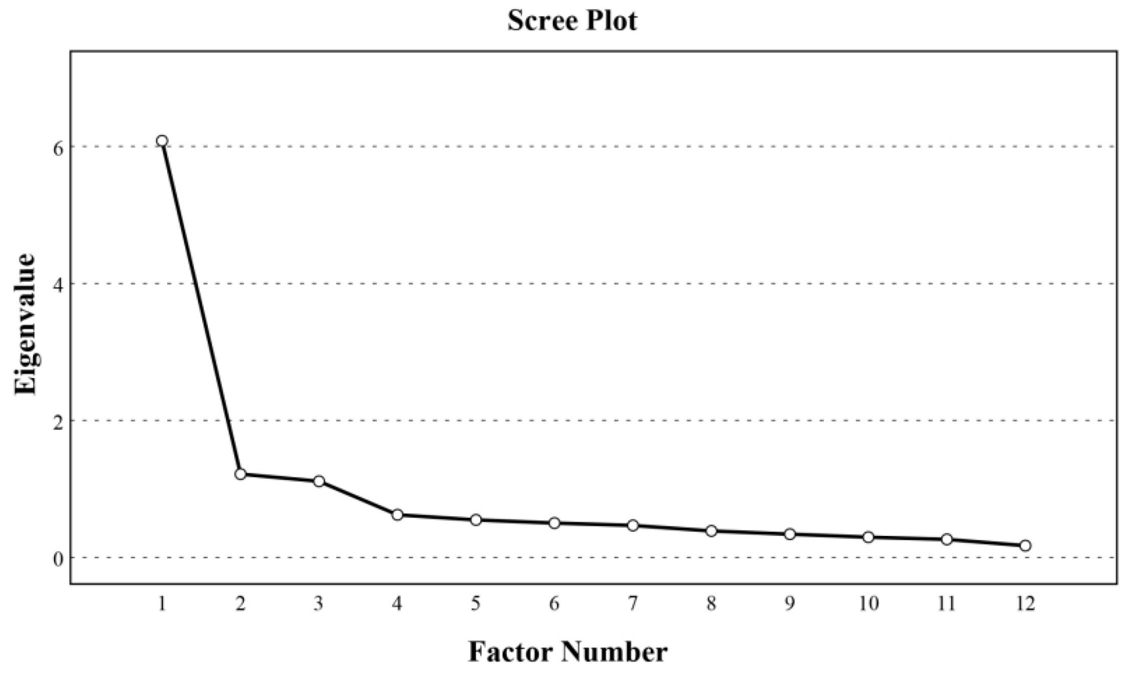

FIGURE 4 | A scree plot for the number of factors to be retained.

respondents received at least junior school education (82.65%), and they had more than 5 years of work experience in the construction industry (86.76%).

Exploratory Factor Analysis

Following steps were performed firstly before the factor extraction process, including numerical conversion of reverse items, recording and scoring reverse items, and assigning new values to old ones. Then, the KMO and Bartlett test were examined to analyze a correlation between original variables, namely whether it was suitable for the factor analysis (Clark and Watson, 1995). The results showed that the KMO value was 0.902 and the significant level of Bartlett test was 0, it indicated an appropriateness of data for the factor analysis.

The scree test and eigenvalue (>1) recommended by Costello and Osborne (2005) were used in combination to decide the number of factors to be extracted (Costello and Osborne, 2005). The graph of eigenvalues in the scree test (**Figure 4**) was studied, and the break point of data where the curve flattened out was identified. Finally, three factors were clearly identified with the consideration of the criteria mentioned; the result was in accordance with the conceptual framework proposed in stage 1. Accordingly, a total of 12 items of the CWISC scale were retained for further analysis after removing six unbefitting items. For the clarity of presentation, factor loadings below 0.3 were not shown in **Table 6** as done in the study of Man et al. (2019). The factor loadings of the 12 items belonging to three dimensions varied from 0.519 to 0.920, and each item had a unique contribution to one of these three factors. The eigenvalues of CSC, SSC, and PSC were 6.081, 1.216, and 1.111, respectively, these dimensions accounted for 70.075% of the total variance.

TABLE 6 | The results of the exploratory factor analysis (EFA).

Item	content	Factor loading			Communality
		SSC	OCSC	PSC	
1	SSC1	0.920			0.787
2	SSC2	0.854			0.760
3	SSC4	0.823			0.711
4	SSC5	0.772			0.753
5	SSC6	0.790			0.646
6	CSC2		0.787		0.649
7	CSC3		0.854		0.648
8	CSC4		0.818		0.669
9	CSC6		0.701		0.573
10	PSC1			0.519	0.724
11	PSC2			0.610	0.717
12	PSC4			0.919	0.772
Eigenvalue cumulative %		6.081	1.216	1.111	
of explanatory variance		50.679	60.815	70.075	

The reliability and validity of the scale were tested to demonstrate their effectiveness. Cronbach coefficient was used to measure the reliability of the questionnaire. In this stage, the overall Cronbach's α of the scale with 12 items was 0.910, the three subscales also obtained excellent internal consistency following that a Cronbach's alpha value above 0.70 was recommended to ensure data reliability (Kim et al., 2021). Cronbach's α of CSC, SSC, and PSC reached 0.810, 0.902, and 0.770. As consequence, all 12 items derived from EFA were worth retaining to the next stage of scale validation.

STUDY 4

Methods

Participants and Procedure

For the verification of item-factor relationships (factor loadings) and the underlying dimensions of the instrument, CFA, one type of structural equation modeling (SEM) (Ullma, 2006), was conducted with a maximum likelihood method. Based on another sample of 156 construction workers, the factor structure derived from stage 3 was incorporated as a measurement model in CFA. This process played an important role in validating the hypothesized model and inspecting the reliability of the measurement. The location of the investigated cities was the same as that in stage 2, and identical distribution and scoring criteria of the questionnaire were employed in this stage. The statistical analysis of workers was depicted in **Figure 5** with the same color and fill formats as **Figure 3**. There was no significant difference between the samples used in the two stages, since fluctuations for the proportion of each part were within 6% (Xie et al., 2021).

Data Analysis

Followed Crawford's and Kelder's suggestions of model fit indices, we reported the Chi-square value (χ^2), root mean square error of approximation (RMSEA), comparative fit index (CFI), Tucker–Lewis's goodness-of-fit index (TLI), and standardized root mean square residual (SRMR) to indicate the model-data fit (Hooper et al., 2008; Kline, 2011). Cronbach's alpha for internal consistency reliability, composite reliability (C.R.), convergent validity, and discriminant validity were also assessed.

Results

Confirmatory Factor Analysis

The three-factor measurement model was tested as illustrated in **Figure 6**. The results revealed a good fit to data. The goodness-of-fit indices were adequate with χ^2 = 68.738, χ^2/df = 1.348, p = 0.049, CFI = 0.976, TLI = 0.968, RMSEA = 0.047, standardized RMR = 0.050, GFI = 0.930, and IFI = 0.976. The values of these goodness-of-fit statistics demonstrated an acceptable model fit (McDonald and Ho, 2002; Kline, 2011).

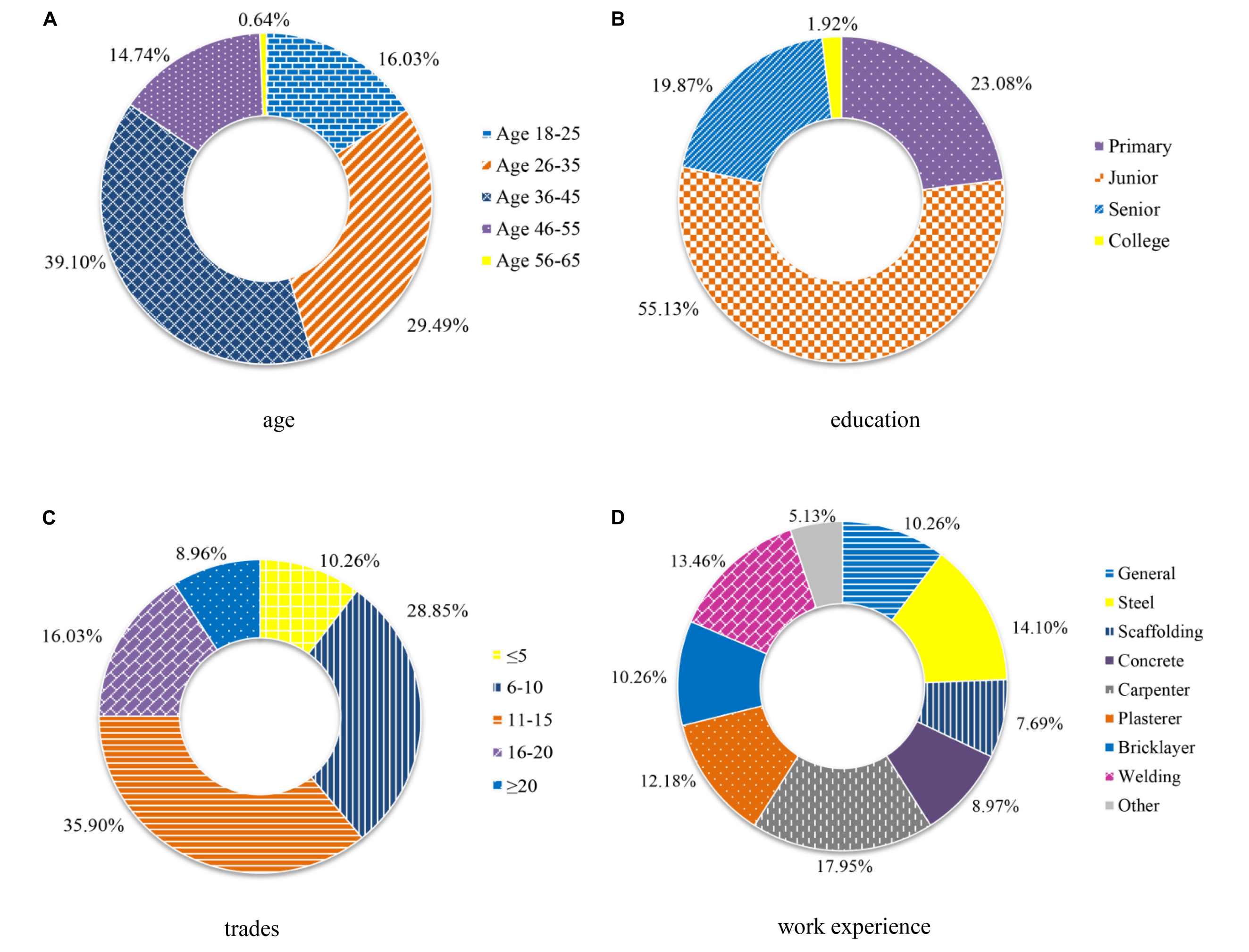

FIGURE 5 | Demographic profiles of workers participated in the confirmatory factor analysis (CFA) in terms of **(A)** age, **(B)** education, **(C)** trades, and **(D)** work experience.

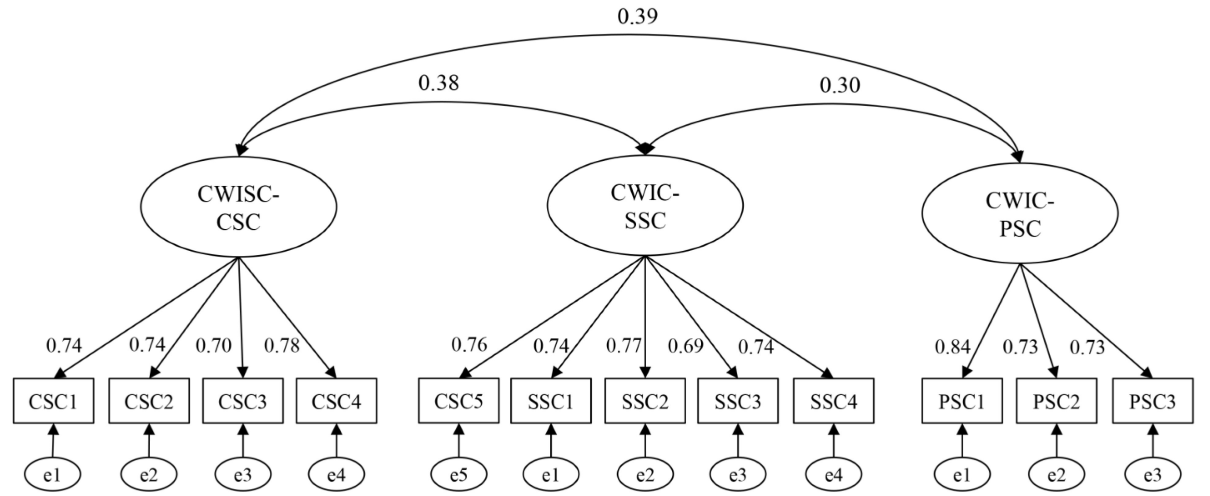

FIGURE 6 | Three-factor measurement model of CWISC with standardized estimates on arrows.

TABLE 7 | Reliability and descriptive statistics of the CWISC scale.

Factor	Item	Factor loading	Cronbach's α	Composite reliability (C.R.)	AVE	Square roots of AVE	*M*	*SD*
SSC			0.856	0.858	0.547	0.740		
	SSC1	0.762					3.62	0.854
	SSC2	0.740					3.69	0.948
	SSC3	0.767					3.46	0.973
	SSC4	0.687					3.43	0.978
	SSC5	0.739					3.48	0.898
CSC			0.829	0.830	0.549	0.741		
	OCSC1	0.736					3.31	0.989
	OCSC2	0.744					3.29	0.979
	OCSC3	0.700					3.22	0.920
	OCSC4	0.782					3.29	0.937
PSC			0.807	0.810	0.589	0.767		
	PSC1	0.836					3.44	1.036
	PSC2	0.732					3.52	0.974
	PSC3	0.729					3.50	0.933

Reliability Assessment

Given that sufficient evidence for the integrity of the factor structure has emerged, its reliability was then assessed. Internal consistency reliability was used to describe the extent to which all items in the scale measured the same concept or construct (Tavakol and Dennick, 2011). With a criterion level of 0.7, Cronbach's alpha was employed to measure internal consistency reliability of the scale (Man et al., 2019). The overall internal reliability of CWISC scale was 0.837, Cronbach's α of subscales and C.R. were shown in **Table 7**. The results showed a range from 0.807 to 0.856 for Cronbach's α of subscales, and a range from 0.810 to 0.858 of C.R., these indicated an acceptable consistency reliability as well as CR.

Validity Assessment

The final stage involved testing for convergent and discriminant validity of the final version of the CWISC scale. Convergent validity, which refers to a correlation between two or more scores on the scale, is designed to assess similar constructs (Chen and Tung, 2014). It can be determined by factor loadings and the average variance extracted (AVE) value for every construct (Fornell and Larcker, 1981). As shown in **Table 7** and **Figure 6**, factor loadings of observed variables were significant between 0.69 and 0.84, the values of AVE were all greater than 0.5. Those statistics illustrated that the convergent validity of the CWISC scale was acceptable (Fornell and Larcker, 1981).

Discriminant validity refers to the extent to which the measure is indeed novel and not simply a reflection of few other variables (Churchill, 1979). The square root of the AVE value was adopted to assess the discriminant validity of the CWISC scale. As shown in **Tables 7**, **8**, all square roots of AVE were greater than construct correlations, which implied discriminant validity to be acceptable (Fornell and Larcker, 1981). Ultimately, based on the processes presented earlier, the final CWISC scale with 12 items was generated.

TABLE 8 | Correlations among constructs.

Constructs	SSC	CSC	PSC
SSC	1.000		
CSC	0.376***	1.000	
PSC	0.299**	0.388***	1.000

***p < 0.01; ***p < 0.001.*

DISCUSSION

The prevalence of CWISC on construction sites and its limited understanding called for the conceptualization and quantification of a construct. Thus, this study presented the development and validation process of the CWISC scale in terms of its ability to measure the communicational characteristics, which were not easy to be detected and rewarded on construction sites. The final scale contained 12 items and three dimensions: CSC, SSC, and PSC. The obtained results indicated that the CWISC had a clear factor structure and adequate metric properties with good validity and reliability, the finding prepared an instrument to aid in understanding and estimating informal safety communication of workers on construction sites.

Construction workers' informal safety communication demonstrated workers' different types of informal safety communication under multiple motivations. As the first dimension, the measurement items of CSC reflected altruistic safety communication in both proactive and passive situations. For instance, proactive CSC was described by workers as "I will tell my workmates how to operate safely when finding him working unsafely," while passive CSC was embodied as "I will tell him if I know when my workmates asking me about safety-related issues." The proposal of proactive CSC was essentially in accordance with the measurement items involved in safety climate (Gao et al., 2017; Zhang et al., 2020) and SCB (Meng and Chan, 2020). As described about "interpersonal helping" in **Table 2**, those descriptions were all actions of initiating CSC. Moreover, the study further reported the passive CSC, which was proved to be another form of participation in altruism-actuated safety communication. This implied that when a worker was asked by coworkers for safety information, the altruistic motivation would facilitate him to respond, it contributed to create a virtuous cycle of SSC–CSC. Conversely, inability to obtain the required safety information will impair the willingness of workers to ask a safety-related question. Considering the discretion of CSC, the results also led to the need to explore incentives, even beyond the formal reward system, to increase workers' positivity to join CSC.

The second dimension, SSC, was closely linked to workers' own safety needs, which can be well explained by Maslow's hierarchy of needs. The theory classified human needs into five grades from low to high, those were physiological needs, safety needs, belonging, esteem, and self-actualization (Maslow, 1943). It described the process of individual's demand chasing, in which the realization of lower-level needs was a prerequisite for individuals to pursue needs at a higher level (Wahba and Bridwell, 1976; Hale et al., 2019). As identified in the second level, safety needs of construction workers was deemed to be primary, only when a worker fulfilled the expected safety requirements for personal and workplace safety, can other subsequent needs be pursued. Despite the fundamental safety needs have pushed SSC to the forefront, it was only mentioned in limited studies as the annotation in **Table 2** "Calling friends on how to handle a work problem" (Allison and Kaminsky, 2017; Chen et al., 2021). More attention needs to be paid considering its priority among three subdimensions of CWISC.

Apparently, in view of the highest mean in three subdimensions and the support from the fundamental safety needs, SSC was evidenced to be the most basic form of safety communication. Moreover, SSC accounted for 50.68% of the total variance, which also indicated that it was a dominant factor. The opinion that workers were considered to be responsible for their own safety was in line with Didla's exposition. In the course of his interviews, workers claimed that it was their duty to keep their own safety, they did not want to be hurt (Didla et al., 2009). However, nearly half of the workers interviewed in this study admitted that they hardly ever asked coworkers for safety information. When ambiguous safety information emerged at work, they felt feasible to follow their own work experiences, this tendency may put themselves into a dangerous situation. Being the least mentioned event during interviews (15), as well as receiving an unexpected low mean score (below 0.4) in the investigation, an urgent need to give particular concerns on exploring the underlying reasons behind workers' experience-preferred operation is also stressed. A cognitive failure of a worker, which is caused by ambiguity or lacking of indispensable safety information, will ultimately lead to the occurrence of unsafe behaviors (Fang et al., 2016).

For the third dimension, PSC and the covered items were defined to evaluate workers' representation on safety information sharing. The measurement items revolving around safety discussion were designed based on existing research, as "I feel comfortable discussing safety issues with my workmates" and "I would like to share my safety operation experience with my workmates." Meanwhile, the result provided a well explanation for the dynamic discussion process under Cognitive Surplus and Herd Mentality. In the state of Cognitive Surplus, experienced workers are willing to share their safety-related knowledge in their rest time, this action was considered to be an important channel for the transmission of tacit knowledge within the crew (Matei, 2012). Additionally, unlike workers who initially engaged in safety discussion with the mindset of sharing information, the participation of some workers was detected to be an efficacy of Herd Mentality. Some workers declared that they joined in the discussion initially just because familiar workers were involved. With the enthusiasm and openness of the discussion gradually increased, they became willing to share their opinions. This phenomenon of conformity was in line with the inspiration from Liang's research, in which workers' safety violations were shown to be contagious within the crew (Liang et al., 2018). This led to the consideration on how to promote the positive effect of Herd Mentality through management interventions. In view of that, open safety discussion provides a shared understanding of expected behaviors and how procedures should be translated into work practices (Michael et al., 2006), efforts should be made to facilitate workers' willing to participate in safety discussion as well as their positive attitude toward PSC.

All three types of CWISC can promote transferring and sharing of safety-related information within crews, they also contribute to the cultivation of risk management capability together with safety awareness of workers. The dynamic process of safety communication produces an important access to achieve self-safety management within the workers group, it further elicits the formation of a worker-centered adaptive system, by which the proactive safety management was expected to achieve. The development and cultivation of proactive self-management should be emphasized and applied in combination with passive management methods, such as the implementation of management interventions. The study is expected to draw attention to the importance of CWISC in follow-up studies.

THEORETICAL IMPLICATIONS

The CWISC framework and the corresponding scale developed in this article are expected to generate the following important theoretical implications. First, the findings of this study reflected the applicability of relevant theories in construction safety research, these provided new explanations for intra-team safety communication. Then, this study was an extension of previous research investigating the communication network in a safety context to increase our understanding on its composition. Following the basic attributes of organizational communication, such as the direction of information transmission and communication channels, the findings provided supportive evidence on the three types of CWISC from the perspective of individual motivation. In particular, a valuable source of information formed by the study provided richer insights into CWISC, these findings had a potential to highlight a disparity within these dimensions. Finally, an in-depth analysis of the construct was helpful to improve the theories of safety communication under the construction background. Theoretically, the CWISC scale, as a multi-tested measurement tool, was a necessary basis for derivative research. It is expected to contribute to the completion of more research focusing on safety communication among workers.

PRACTICAL IMPLICATIONS

Apart from theoretical implications, this research also generated the following practical implications. Initially, through the adoption of the proposed CWISC scale, managerial benefits may be obtained in developing and implementing effective safety management strategies. The scale can serve as an instrument to assess the performances and tendency of workers' safety communication, the results may help in identifying weaknesses in safety communication. Consequently, wasted management costs could be avoided by selecting and implementing the targeted incentive programs. Further, the practice issue of poor performances within workers' responsibilities was identified and highlighted. The authors believe that there are a mixed set of reasons for the poor SSC on construction sites, such information will hopefully increase the attention of managers and researchers to the problem. Finally, the management intervention of setting up model workers to inspire coworkers' passions for safe communication is recommended to be carried out. It is expected that the CWISC scale could lead to a diverse approach in practice to authenticate and augment workers' safety communication performances.

LIMITATIONS AND FUTURE RESEARCH

Despite contributions of the proposed CWISC framework and its corresponding scale, its limitations must be recognized and future research should be conducted. Although the CWISC scale is expected to have applicability across different countries, the findings of this study were limited to the construction industry in China, it is necessary to further verify its validity in other countries. Then, given the difficulty and limitation of data acquisition, 219 samples and 156 samples were used in EFA and CFA, respectively; a larger sample size should be employed in follow-up studies to validate the developed scale. In addition, there are many sociodemographic factors (e.g., education, work experience, and trade) that could affect safety communication behaviors. It is worthwhile to expand research in this area to obtain a full picture of the CWISC phenomenon. Finally, the study gave a particular focus on CWISC itself to dissect its classification and relative characteristics, efforts should be made in future studies to explore its facilitators and inhibitors. The predictability of CWISC on safety culture or other indicators of safety performance is also suggested for examination. Considering the important role of CWISC on safety performance in the context of construction, abundant research will provide valuable references for the development of management measures.

CONCLUSION

Construction workers' informal safety communication has always been unavoidable on construction sites. By conducting a four-phase deductive–inductive study with a qualitative and quantitative analysis, a comprehensive measurement instrument was developed and validated, the CWISC scale with 12 items was designed to assess workers' communication performances on construction sites. In addition, three dimensions of CWISC, CSC, SSC, and PSC, were identified. Given the lack of concern on exploring the framework and measurement scale of CWISC, it may provide a distinct contribution to theory building and assessment practice on intra-crew safety communication. Moreover, the theoretical and practical implications will draw the attention of managers and researchers to consider the management issues related to it. Despite the useful results of this study, additional works should be carried out to further validate the scale under different backgrounds; its limitations should also be addressed in the future. We expect that the study can lead to diverse research in which the three-dimensional construct of CWISC will be taken into account.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

WC and YS put forward the research idea and promoted the implementation and completion of this research. SZ, HL, and HX supported the data collection. WC involved in statistical analysis, the interpretation of the results, and composing the first draft. HL and HX gave help to further optimize and complete this manuscript. All authors contributed to this article and approved the submitted version.

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Developing a Decision-Making Model for Construction Safety Behavior Supervision: An Evolutionary Game Theory-*Based* Analysis

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Without the active participation of enterprises and front-line workers, it is difficult for the government to perform effective supervision to ensure behavioral safety among front-line workers. To overcome inadequate government supervision and information attenuation caused by vertical management mode and limited resources, and to change passive supervision into active control with the proactive participation of enterprises and workers, this paper combines the entity responsibility mechanism and the third-party participation mechanism based on government supervision to analyze the decision-making process of government and enterprises on safety behavior supervision. An evolutionary game model was established to describe the decision-making interactions between the government and construction enterprises under the two mechanisms, and a simulation was performed to illustrate the factors influencing the implementation of the mechanisms. The results show that both mechanisms have a positive effect on government supervision, and the third-party participation mechanism was found to be working better. The implementation of the two mechanisms is influenced by punishment, subsidy, and cost, and it has different sensitivities to the three influencing factors. This study provides a theoretical framework for enhancing the government supervision mechanism, and the decision-making between the government and construction enterprises enhances the management form and guides their actual supervision practices.

Keywords: construction safety supervision, decision-making model, the enterprise entity responsibility mechanism, the third-party participation mechanism, evolutionary game theory

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INTRODUCTION

Accidents in the construction industry have been a serious global issue for a long time; moreover, industrial safety is a matter of utmost significance (Jin et al., 2020; Li Z. et al., 2021). The government, as an external constraint force, has been recognized as critical for construction safety (Zeng and Chen, 2015), however, the statistics on industrial accident casualties indicate that there are still some defects in government supervision. On the one hand, a lack of personnel and resources results in inadequate government supervision (Cao and Du, 2018; Gong et al., 2021). On the other hand, China's safety supervision system adopts vertical management, which entails that government supervision of construction safety is unified management and hierarchical responsibility (Ma and Zhao, 2018). Under these circumstances, government supervision is limited by the attenuation of the level-by-level effect, such that the unsafe behavior of front-line workers, which is the primary and immediate cause of accidents, cannot be controlled at a fundamental level (Blackmon and Gramopadhye, 1995; Li et al., 2017; Yu et al., 2017). Construction enterprises are the main decision-makers when it comes to safe production. They can directly supervise front-line workers, and the government can mobilize enterprises to jointly participate in the mission of safe production and safety supervision to improve the supervision of front-line workers (Bu, 2016a). Furthermore, when there is an excess workload, enterprises can employ a third party, which specializes in supervision, to control the unsafe behavior of employees, thus avoiding the lack of professional supervision of enterprises and sharing the responsibility. Therefore, based on government supervision, it is imperative to explore a more proactive and professional supervision pathway that can realize active control before an accident occurs and strengthen the efficiency of government supervision.

Previous studies have focused on passive supervision mechanisms, including safety-related regulations and information systems, to control the unsafe behavior of front-line workers (Koh and Rowlinson, 2012; Pi et al., 2019; Fang et al., 2020). However, to promote effective supervision, previous research mostly optimizes the supervision mechanism from the perspective of the government (Guo et al., 2018), lacks the combination of the government's passive safety supervision and enterprises' active safety supervision, and does not emphasize the decision-making process between the government and enterprises. However, from the government's perspective, regardless of the measures implemented, the hierarchical supervision mode of the government cannot be changed. Information asymmetry, which leads to the behavior of the liability subject, cannot be effectively restrained. Therefore, decision-making interactions between the government and enterprises in safety supervision must be analyzed.

To solve the problems of information attenuation and inadequate government supervision, we explored a safety supervision mode that implements the enterprise entity responsibility mechanism (Lu, 2020) and third-party participation mechanism (Zhu and Chen, 2015; Li X. C. et al., 2021) based on the government supervision. The enterprise entity responsibility mechanism means that the enterprise is the main body of responsibility for production safety, and the chief person in charge is the first person responsible for production safety, who takes the initiative to fulfill the work safety responsibility. The third-party participation mechanism refers to enterprises implementing a third-party safety supervision organization that is independent of the government or construction enterprises to provide professional, objective, and fair safety supervision services for the construction enterprises. Differences in interests and objectives lead to construction safety supervision under the two mechanisms of a game process between government and construction enterprises (Bu, 2016a). To better examine the dynamic change process of construction safety supervision, this study introduces the evolutionary game theory to analyze the behaviors of different subjects. Simultaneously, the punishment, subsidy, and probability of accidents under different supervision mechanisms are considered in the game model, which makes the research more realistic.

In contrast to previous studies, herein, we focus on the choice of supervision mechanism in different scenarios from the perspective of enterprises and their influence on government supervision decision-making. Therefore, to verify the effectiveness and to promote the implementation of the two abovementioned mechanisms for government safety supervision, the decision-making interactions of government and construction enterprises were quantitatively analyzed to ascertain the behavioral characteristics. Furthermore, in this study, the equilibrium points of the game system were simulated to validate and compare the two mechanisms to prove the effectiveness of supervision. Corresponding suggestions were put forward on the degree of government subsidies and punishments for construction enterprises according to the analysis results. This study presents the realistic supervision process under two mechanisms. The model describes the decision-making interactions between construction enterprises and the government and reveals the inherent law in the supervision process, which not only enhances the supervision mechanism, but also contributes to government policy formulation and enterprise supervision.

LITERATURE REVIEW

Construction Safety Supervision

Safety supervision refers to the comprehensive supervision and inspection of the safety conditions and implementation of the safety responsibilities of the relevant subjects by the construction administrative departments and relevant government departments in accordance with laws, regulations, and relevant standards (Cheng et al., 2013). The problems of the hierarchical supervision mode in China have facilitated extensive studies on designing effective safety incentive mechanisms and led to changes in the passive situations of construction safety to realize active control, that is, implementation of certain measures that urge the enterprises to give more emphasis to the safety management and form an enterprise-based self-operation mechanism of safety management. For example, it has been proposed that successful safety supervision largely depends on employee involvement, as workers tend to support the activities that they themselves help to create (Aksorn and Hadikusumo, 2008). Next, some research focused on the structure of responsibility, incentives, and penalties in the enterprises, which reencourage positivity and creativity among workers, resulting in conscious observation of all kinds of safety rules and regulations for production and accomplishment of the goal (Liang, 2006; Ji et al., 2021). The relationship between project safety performance and the influence of construction enterprises has been examined (Hallowell, 2010). Owners are making efforts to improve project safety performance, with a focus on achieving the goal of zero injuries, selecting safe contractors, and developing a safety culture on their projects through safety training and safety recognition programs (Huang and Hinze, 2006). A double closed-loop feedback control system based on the security problems of development and construction units has been proposed to promote the efficiency of safety supervision (Bu, 2016b). In addition, a type of engineering construction safety consultant model has been proposed. In other words, a professional agency is entrusted with carrying out on-site safety management. Professional safety engineers take full advantage of their knowledge and experience and they have significantly improved the management level of development organizations (Liu et al., 2013).

In general, the above research proves that the participation of enterprises, employees, and third parties can strengthen the effectiveness of government supervision. However, most existing studies focus only on the effect of an enterprises' active supervision on safety supervision performance. As the government is the main body of supervision, government supervision is indispensable. The following factors need to be explored: (1) The effect of active supervision of enterprises on the decision-making of government supervision. (2) Ways to coordinate both active and government supervision to achieve optimal decision-making strategies. It is a game process between enterprises' active supervision and the government's passive supervision; therefore, it is necessary to abstract the practical problems of supervision in the game model and study the interactive decision-making between them to promote active control and improve the efficiency of government supervision.

Evolutionary Game Theory in Construction Safety Supervision

To better examine the process of safety supervision, the evolutionary game theory was introduced to analyze the behaviors of different subjects. Compared to the classical game theory, the evolutionary game theory is a combination of game theory and dynamic evolution process analyses, and it focuses more on the dynamics of strategy change (Weibull, 1997). Supervision is a controllable process, and the study of evolutionary games is beneficial to excavate the decision logic behind the behaviors of stakeholders and to reduce or even avoid accidents at the root (Tang et al., 2021).

To analyze the key factors of a stable construction safety supervision, an evolutionary game model has been presented, which demonstrates the need to introduce an appropriate external supervision and restraint mechanism that enhances both sides to control safety risk (Zeng and Chen, 2015). Some scholars have established a game model of government departments, as well as upstream and downstream participants to examine the effectiveness of China's construction project quality supervision system and proposed a dynamic punishment and incentive method (Feng et al., 2020). In addition, the behavioral strategy choices and the change in the stable state of the production staff and safety supervisor under different scenarios are discussed. The results showed that the stable state of unsafe employee behavior supervision was not related to profit (Shi et al., 2018). Other scholars have analyzed the interaction of project owners, supervision engineers, and construction contractors in construction quality supervision and verified that the dynamic reward and punishment mechanism can improve the quality of the supervision procedure (Guo et al., 2018).

In summary, the evolutionary game theory approach has been gradually introduced in various studies to analyze construction safety supervision behaviors in engineering projects. However, most existing studies have focused on illustrating the game process between the main participants in supervision and safety production; however, the reports are not convincing enough to regard construction enterprises as active supervision participants and explore decision-making interactions with the government. At the same time, the existing research lacks a comparison of the different active supervision mechanisms. Therefore, an evolutionary game model between the government and construction enterprises is formulated, and the decision-making interactions are described. The impact factors of implementing the two mechanisms by enterprises in different scenarios are analyzed and compared to provide constructive suggestions for the enthusiasm of enterprises and optimizing safety supervision mechanisms.

CONSTRUCTION SAFETY SUPERVISION DECISION-MAKING MODEL

In this study, two supervision mechanisms, i.e., the enterprise entity responsibility and the third-party participation mechanisms, are added to the game model between construction enterprises and the government. At the same time, the decision paths and stable strategies are demonstrated, in which the influence of the bounded rationality of both sides is considered. The game analysis process for construction safety supervision is illustrated in **Figure 1**.

Assumptions

To analyze the safety supervision in the construction field, we made the following assumptions under the two supervision mechanisms.

Assumption 1: The game has two participants, namely the government and construction enterprises, and both parties have two strategies to choose from. The government performs supervision over the construction operations to (1) avoid adverse effects from accidents, and (2) provide a cost-effective service of real-time monitoring of all construction enterprises under jurisdiction, since it is quite expensive; thus, they will choose the strength of safety supervision. Therefore, the government's strategy is {strict supervision G_{i1}, ordinary supervision G_{i2}}. ($i = 1$ and $i = 2$ represent the two mechanisms). Ordinary supervision entails that, based on completing policy formulation and rulemaking, the government will conduct random inspections of enterprises according to the probability of β. While on one hand, strict supervision means that in addition to ordinary safety supervision, the scope of supervision is enhanced; on the other hand, punishment is increased, and the safety behavior of

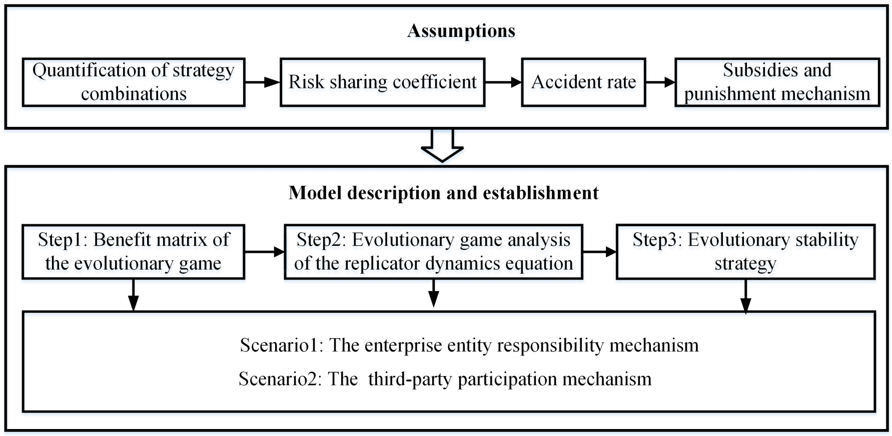

FIGURE 1 | The game analysis process of construction safety supervision.

enterprises is more strictly supervised. Moreover, the behavioral strategy set of the construction enterprises is {implementing the mechanism C_{i1}, not implementing the mechanism C_{i2}}. The probabilities of the construction enterprises choosing the "implementing the mechanism" or "not implementing the mechanism" strategies are x and 1-x, respectively. The probabilities of the government choosing the "strict supervision" or "ordinary supervision" strategies are y and 1-y, respectively.

Assumption 2: Referring to Yu et al. (2020) and Meng et al. (2021), the participants in the game are required to share the loss of the liability cost reasonably, and the loss of the liability cost is linearly related (the correlation coefficient is a real number greater than 0). That is, if construction enterprises bear a liability cost loss of C, then the government bears a liability cost loss of kC, where k is the transfer coefficient of the liability cost loss.

Assumption 3: According to He et al. (2020) and Wu et al. (2020), the capabilities of both players have complementary effects. In other words, when the construction enterprises implement the mechanism under strict government supervision, the possibility of accidents is minimal. Without loss of generality, we assume that the accident cost loss is zero in this case. When one side chooses ordinary safety management while the other side chooses to implement the mechanism, the probability of accidents increases. When both sides adopt opposing safety management strategies, the probability of risk loss is the greatest, we assume that an accident must occur.

Assumption 4: According to the "Production Safety Law of the People's Republic of China," the state will reward units and individuals that have made remarkable achievements in improving production safety conditions, preventing production safety accidents, and participating in emergency rescue. It also clearly stipulates that the violations of safety production found during the inspection shall be corrected on the spot or corrected within a specified time limit. For acts that should be given administrative penalties according to the law, administrative penalty decisions shall be made. We assumed that no matter what the government chooses between strict supervision and ordinary supervision, subsidies will be given to enterprises that implement the two mechanisms. When enterprises do not implement the two mechanisms and the government performs strict supervision, enterprises will be punished. When the government chooses ordinary supervision, since it only completes the most basic policy formulation and supervision tasks, the intensity of supervision and punishment is small, so the cost of punishment is ignored under this circumstance. Based on the above assumptions, we established a game model for the government and enterprises under the two mechanisms, i.e., the entity responsibility mechanism and the third-party participation mechanism.

Model Description and Establishment

Scenario 1: The Enterprise Entity Responsibility Mechanism

Step 1. *Benefit matrix of the evolutionary game*

Under the enterprise entity responsibility mechanism, the construction enterprises undertake the most direct and important responsibility in the construction process, which entails those enterprises are willing to invest more in safety supervision and actively carry out safety management to avoid safety accidents. When the probability of safety accidents is reduced, the government can get rewards from superior departments and praise from the public, and the shared cost of the accidents is also reduced. Therefore, for construction enterprises, the cost, and subsidies for implementing the mechanism are C_{c1} and S_1, respectively. If construction enterprises fail to fulfill the entity responsibility, the loss caused by the accidents is L_1, and they will be fined F_1 by the government. For the government, when it adopts strict supervision, the work cost is C_{g1} and the benefits from superior departments and increased public credibility are R_1. In contrast, when the government chooses ordinary supervision, the work cost is βC_{g1} $(0 < \beta < 1)$, and it will lose reputation M_1 if an accident occurs. When enterprises implement the mechanism and the government chooses ordinary supervision, the probability of accidents is h $(0 < h < 1)$; when enterprises do not use the mechanism and the government chooses strict supervision, the probability of accidents is g ($0 < g < 1$). Because enterprises can share part of the government's supervision tasks, it is assumed that $g > h$. Finally, the transfer coefficient of the liability cost loss by the government is k.

According to these assumptions, the benefit matrix of the government and construction enterprises under enterprise entity responsibility can be constructed, as shown in **Table 1**.

Step 2. *Evolutionary game analysis of the replicator dynamics equation*

According to the replication dynamic equation, the benefits of implementing the entity responsibility mechanism and not implementing the enterprise entity responsibility mechanism for construction enterprises are determined as follows:

$$U_{C_{11}} = y\left(-C_{c1} + S_1\right) + \left(1 - y\right)\left(-C_{c1} + S_1 - hL_1\right) = -C_{c1} + S_1 + hL_1\left(y - 1\right) \quad (1)$$

$$U_{C_{12}} = y\left(-F_1 - gL_1\right) + \left(1 - y\right)\left(-L_1\right) = -yF_1 - ygL_1 + yL_1 - L_1 \quad (2)$$

The replication dynamic equations for the construction enterprises are:

$$F(x) = \frac{d_x}{d_t} = x\left(U_{C_{11}} - \overline{U_{C_1}}\right) = x(1-x)\left(U_{C_{11}} - U_{C_{12}}\right) = x(1-x)[y\left(hL_1 + F_1 + gL_1 - L_1\right) + S_1 - C_{c1} + L_1 - hL_1] \quad (3)$$

The benefits of strict and ordinary supervision by the government are determined as follows:

$$U_{G_{11}} = x\left(R_1 - C_{g1} - S_1\right) + (1-x)\left(R_1 - C_{g1} + F_1 - kgL_1\right) = x\left(kgL_1 - F_1 - S_1\right) + R_1 - C_{g1} + F_1 - kgL_1 \quad (4)$$

$$U_{G_{12}} = x\left(R_1 - \beta C_{g1} - S_1 - khL_1 - hM_1\right) + (1-x)\left(-\beta C_{g1} - kL_1\right) = x\left(R_1 - S_1 - khL_1 + kL_1 - hM_1\right) - \beta C_{g1} - kL_1 \quad (5)$$

TABLE 1 | The benefit matrix between government and construction enterprises.

Construction enterprises	**Government**	
	Strict supervision (*y*)	**Ordinary supervision (1-*year*)**
Implementing the mechanism(x)	$-Cc_1+S_1$,$R1$-C_{g1}–S_1	$-Cc_1+S_1-hL_1$, $R_1-\beta C_{g1}-S_1-h(kL_1+M_1)$
Not implementing the mechanism(1-x)	$-F_1$-gL_1, $R_1-C_{g1}+F_1-kgL_1$	$-L_1$, $-\beta Cg_1-kL_1$

The government will constantly learn and adjust its strategies based on changes in benefits, resulting in vibrations in strategic choices. The replication dynamic equations for the government are as follows:

$$F\left(y\right) = \frac{d_y}{d_t} = y\left(U_{G_{11}} - \overline{U_{G_1}}\right) = y(1-y)\left(U_{G_{11}} - U_{G_{12}}\right) = y(1-y)\left\{x\left[kL_1\left(g + h - 1\right) - F_1 + hM_1 - R_1\right] + R_1 + (\beta - 1)C_{g1} + \left(1 - g\right)kL_1 + F_1\right\} \quad (6)$$

For dynamic equations (3) and (6), let $F(x) = 0$ and $F(y) = 0$; Concurrently, we can discuss the evolutionary stability strategy of the system.

The equilibrium points existing in the replication dynamic equation system are as follows:

There are four fixed equilibrium points in the system: (0,0), (0,1), (1,0), and (1,1). There is another equilibrium point (x^*, y^*), where $x^* = \dfrac{R_1 + (\beta - 1)C_{g1} + \left(1 - g\right)kL_1 + F_1}{R_1 + F_1 - hM_1 - kL_1\left(h + g - 1\right)}$ and $y^* = \dfrac{C_{c1} + \left(h - 1\right)L_1 - S_1}{\left(h + g - 1\right)L_1 + F_1}$, when Eq. (7) are satisfied.

$$\left.\begin{array}{l} 0 \le \dfrac{C_{c1} + \left(h - 1\right)L_1 - S_1}{\left(h + g - 1\right)L_1 + F_1} \le 1 \\ 0 \le \dfrac{R_1 + F_1 + (\beta - 1)C_{g1} + \left(1 - g\right)kL_1}{R_1 + F_1 - hM_1 - kL_1\left(h + g - 1\right)} \le 1 \end{array}\right\} \quad (7)$$

Step 3. *Evolutionary stability strategy*

According to the method proposed by Friedman, the evolutionary stable strategy (ESS) of the differential equation system can be obtained from the local stability analysis of the Jacobian matrix J of the system, that is, if the Determinant J ($DetJ$) > 0 and Trace J (TrJ) < 0, the point is locally stable. Equations (3) and (6) constitute the system of equations whose Jacobian matrix is

$$J = \begin{bmatrix} (1-2x)\left[y\left(hL_1 + F_1 + gL_1 - L_1\right) + S_1 - C_{c1} + L_1 - hL_1\right] & x\left(1-x\right)\left(hL_1 + F_1 + gL_1 - L_1\right) \\ y\left(1-y\right)\left[kL_1\left(g + h - 1\right) - F_1 + hM_1 - R_1\right] & \left(1 - 2y\right)\left\{\begin{array}{l} x\left[kL_1\left(g + h - 1\right) - F_1 + hM_1 - R_1\right] \\ + R_1 + (\beta - 1)C_{g1} + \left(1 - g\right)kL_1 + F_1 \end{array}\right\} \end{bmatrix} \quad (8)$$

$Det\ J$ and $Tr\ J$ calculation formulas for each equilibrium point in scenario 1 are listed in **Table 2**. Given that $h + g = 1$ is fixed, and the rewards and reputation gains from strict government supervision R_1 are greater than the reputation losses in the event of an accident M_1, therefore, $R_1 + (\beta-1)\ C_{g1} + F_1 + (1-g)\ kL_1 > (\beta-1)\ C_{g1} + khL_1 + hM_1$, $S_1 + F_1 + gL_1 > S_1 + L_1 - hL_1$.

There are nine different evolutionary stability strategies in different initial states, which are extracted in **Supplementary Appendix 1**. Various equilibrium scenarios are analyzed below.

TABLE 2 | The formula of the determinant for each equilibrium point.

Equilibrium point	DetJ	TrJ
(0,0)	$(S_1+L_1-hL_1-C_{c1}).[R_1+(\beta-1)C_{g1}+F_1+(1-g)kL_1]$	$(S_1+L_1-hL_1-C_{c1})+[R_1+(\beta-1)C_{g1}+F_1+(1-g)kL_1]$
(0,1)	$(S_1-C_{c1}+F_1+gL_1)[(1-\beta)C_{g1}-R_1-F_1\text{-}(1-g)kL_1]$	$(S_1-C_{c1}+F_1+gL_1)+[(1-\beta)C_{g1}-R_1-F_1\text{-}(1-g)kL_1]$
(1,0)	$(C_{c1}-S_1-L_1+hL_1).[(\beta-1)C_{g1}+khL_1+hM_1]$	$(C_{c1}-S_1\text{-}L_1+hL_1)+[(\beta-1)C_{g1}+khL_1+hM_1]$
(1,1)	$(C_{c1}-S_1-F_1-gL_1).[(1-\beta)C_{g1}-khL_1-hM_1]$	$(C_{c1}-S_1-F_1-gL_1)+[(1-\beta)C_{g1}-khL_1-hM_1]$

(1) When the factors satisfy $C_{c1} < S_1 + L_1–hL_1 < S_1 + F_1 + gL_1$, and $(\beta–1)\ C_{g1} + khL_1 + hM_1 > 0$, the equilibrium point is (1,1), which means that regardless of the government's strategy, the subsidy and income saved by preventing accidents and punishment are greater than the cost of implementing the entity responsibility mechanism, and construction enterprises will choose to implement the mechanism based on income. In addition, regardless of the strategy of construction enterprises, the cost of strict supervision by the government is less than the cost of accidents, and the government chooses a strict supervision strategy.

(2) When the factors satisfy $C_{c1} < S_1 + L_1–hL_1 < S_1 + F_1 + gL_1$, and $R_1 + (\beta–1)\ Cg_1 + F_1 + (1–g)\ kL_1 < 0$, the equilibrium point is (1,0). That is, regardless of the government's strategy, the economic benefits are greater than the cost of implementing the entity responsibility mechanism by the construction enterprises. Therefore, construction enterprises have chosen to implement this mechanism. In addition, regardless of the strategy of construction enterprises, enforcement of stricter supervision by the government will increase the supervision cost. Therefore, the government has adopted an ordinary supervision strategy.

(3) When $C_{c1} < S_1 + L_1–hL_1 < S_1 + F_1 + gL_1$, and $(\beta–1)\ C_{g1} + khL_1 + hM_1 < 0 < (\beta–1)\ Cg_1 + R_1 + F_1 + (1–g)\ kL_1$, the equilibrium point is (1,0), that is, whatever the government chooses, the cost paid by the construction for implementing the entity responsibility mechanism is less than the performance delivered by the mechanism; therefore, construction enterprises will implement the entity responsibility mechanism. The benefit from the government is affected by the construction enterprises, that is strict government supervision is less beneficial than that of the ordinary supervision adopted by construction enterprises implementing the entity responsibility mechanism. Thus, governments tend to choose ordinary supervision.

(4) When $S_1 + L_1–hL_1 < S_1 + F_1 + gL_1 < C_{c1}$, and $(1–\beta)\ C_{g1} < khL_1 + hM_1$, the equilibrium point is (0,1), meaning, regardless of the government's strategy, the cost paid by construction enterprises is greater than the income from implementing the entity responsibility mechanism. Therefore, from an income perspective, the construction enterprises will choose not to implement the mechanism. In addition, regardless of the strategy adopted by construction enterprises, the cost of strict supervision by the government is less than the cost of accidents and consequently, the government chooses a strict supervision strategy.

(5) When $S_1 + L_1–hL_1 < S_1 + F_1 + gL_1 < C_{c1}$ and $(1–\beta)\ C_{g1} > R_1 + F_1 + (1–g)\ kL_1$, the equilibrium point is (0,0), meaning, regardless of the government's strategy, the economic benefits are less than the cost of implementing the entity responsibility mechanism by construction enterprises, and therefore construction enterprises choose not to implement the mechanism based on income. In addition, regardless of the construction enterprises' strategy, the overall benefit obtained from ordinary supervision is greater than that obtained using strict supervision by the government; therefore, it is disadvantageous to incentivize the government to take strict supervision.

(6) When $S_1 + L_1–hL_1 < S_1 + F_1 + gL_1 < C_{c1}$, and $(\beta–1)\ C_{g1} + khL_1 + hM_1 < 0 < R_1 + F_1 + (\beta–1)\ Cg_1 + (1–g)\ kL_1$, the equilibrium point is (0,1). That is, regardless of the government's choice, construction enterprises will not implement an entity responsibility mechanism. The benefits of the government are affected by the construction enterprises, and the cost saved through ordinary government supervision is less than the strict supervision performance when construction enterprises are not implementing the entity responsibility mechanism. Therefore, the government tends to choose strict supervision.

(7) When the factors satisfy the conditions $S_1 + L_1–hL_1 < C_{c1} < S_1 + F_1 + gL_1$ and $(1–\beta)\ C_{g1} < khL_1 + hM_1$, the equilibrium point is (1,1). Therefore, regardless of the strategy adopted by construction enterprises, the benefit of strict supervision by the government is greater than that of ordinary supervision. The construction enterprises benefits are affected by the government. when the government chooses strict supervision, not implementing the mechanism is less beneficial than implementing the mechanism. Thus, construction enterprises are inclined to implement the mechanism strategy.

(8) When the factors satisfy $S_1 + L_1–hL_1 < C_{c1} < S_1 + F_1 + gL_1$ and $(1–\beta)\ C_{g1} > R_1 + F_1 + (1–g)\ kL_1$, the equilibrium point is (0,0). meaning, regardless of the choice made by construction enterprises, the government will choose ordinary supervision. The construction enterprises benefits are affected by the government; therefore, construction enterprises will not implement the entity responsibility mechanism when the government adopts ordinary supervision.

(9) When the factors satisfy the condition $S_1 + L_1–hL_1 < C_{c1} < S_1 + F_1 + gL_1$ and $(\beta–1)\ C_{g1} + khL_1 + hM_1 < 0 < (\beta–1)\ Cg_1 + R_1 + F_1 + (1–g)\ kL_1$, the replicated dynamic equation is asymptotically stable at point (x^*, y^*), the decision-making of both parties influences each other, and the decisions of the two participants depend on the change in the threshold, which is related to factors S_1, L_1, C_{C1}, and F_1.

Scenario 2: The Third-Party Participation Mechanism

***Step 1**. Benefit matrix of the evolutionary game*

Third-party institutions are supervision and management institutions entrusted by the government or contractors to provide professional, fair, and objective safety supervision services in a compensatory manner. The government's supervision cost is C_{g2}. In addition, construction enterprises employ third-party institutions to solve safety management problems, which increases the safety investment cost of construction enterprises, but reduces the probability of production safety accidents; the cost of safety management will be C_{c2} ($C_{c2} > C_{c1}$). The definitions of the other related parameters are the same as those in Scenario 1. A payoff matrix between the government and construction enterprises under the third-party participation mechanism was established, as shown in **Table 3**. Third-party supervision institutions are more professional in safety supervision. Therefore, when the government chooses ordinary supervision and enterprises implement the mechanism, which can avoid the problems of slackness and insufficient resources in the process of enterprises supervision, the probability of accidents decreases from h in scenario 1 to $h(1\text{-}\alpha)$. α in $h(1\text{-}\alpha)$ represents the supervision effects of the third-party.

Step 2. *Evolutionary game analysis of the replicator dynamics equation*

The replication dynamic equation for the construction enterprises is:

$$F(x) = \frac{d_x}{d_t} = x\left(U_{C_{21}} - \overline{U_{C_2}}\right) = x(1-x)\left(U_{C_{21}} - U_{C_{22}}\right)$$
$$= x(1-x)\left\{y\left[F_2 + h(1-\alpha)L_2 - (1-g)L_2\right] + S_2 - C_{c2} - h(1-\alpha)L_2 + L_2\right\} \quad (9)$$

For the government, the benefits of implementing the third-party participation mechanism and not implementing the mechanism are determined as follows:

The replication dynamic equation for the government is:

$$F(y) = \frac{d_y}{d_t} = y\left(U_{G_{21}} - \overline{U_{G_2}}\right) = y(1-y)\left(U_{G_{21}} - U_{G_{22}}\right)$$
$$= y(1-y)\left\{x\left[kL_2(g-1) + h(1-\alpha)(kL_2+M_2) - R_2 - F_2\right] + R_2 + (\beta-1)C_{g2} + F_2 + kL_2(1-g)\right\} \quad (10)$$

For the dynamic Eqs (9) and (10), let $F(x) = 0$ and $F(y) = 0$. Concurrently, we can discuss the evolutionary stability strategy of the system.

The equilibrium points in the replication dynamic equation system in scenario 2 are as follows:

There are four fixed equilibrium points in the system: (0,0), (0,1), (1,0), and (1,1). There is another equilibrium point (x^*,y^*), where

$$x^* = \frac{R_2 + F_2 + (\beta-1)C_{g2} + kL_2(1-g)}{R_2 + F_2 + kL_2(1-g) - (kL_2+M_2)h(1-\alpha)}$$

and

$$y^* = \frac{S_2 - C_{c2} - h(1-\alpha)L_2 + L_2}{(1-g)L_2 - h(1-\alpha)L_2 - F_2},$$

when

$$0 \le \frac{R_2 + (\beta-1)C_{g2} + F_2 + kL_2(1-g)}{R_2 + F_2 + kL_2(1-g) - (kL_2+M_2)h(1-\alpha)} \le 1,$$

and

$$0 \le \frac{S_2 - C_{c2} - h(1-\alpha)L_2 + L_2}{(1-g)L_2 - h(1-\alpha)L_2 - F_2} \le 1.$$

Step 3. *Evolutionary stability strategy*

Equations (9) and (10) constitute the system of the equations, and the Jacobian matrix in scenario 2 is as follows:

$$J = \begin{bmatrix} (1-2x)\left\{\begin{array}{l} y\left[h(1-\alpha)L_2 - (1-g)L_2 + F_2\right] \\ +S_2 - C_{c2} - h(1-\alpha)L_2 + L_2 \end{array}\right\} & x(1-x)\left[h(1-\alpha)L_2 - (1-g)L_2 + F_2\right] \\ y(1-y)\left[\begin{array}{l} kL_2(g-1) + h(1-\alpha) \\ (kL_2+M_2) - R_2 - F_2 \end{array}\right] & (1-2y)\left\{\begin{array}{l} x[kL_2(g-1) - F_2 - R_2 + h(1-\alpha) \\ (kL_2+M_2)] + R_2 + (\beta-1)C_{g2} + F_2 \\ +kL_2(1-g) \end{array}\right\} \end{bmatrix} \quad (11)$$

Det J and *Tr J* calculation formulas for each equilibrium point in scenario 2 are listed in **Table 4**. It is assumed that $R_2 > M_2$, and thus $(\beta-1)\,C_{g2} + R_2 + F_2 + kL_2\,(1-g) > (\beta-1)\,C_{g2} + h\,(1-\alpha)\,(kL_2 + M_2)$.

We analyze various equilibrium scenarios below, and there are 11 different evolutionary stability strategies in different initial states, which are summarized in **Supplementary Appendix 2**. For the sake of explaining, we simplified the 11 scenarios into seven scenarios.

(1) For construction enterprises, when the factors satisfy $Cc_2 > S_2 + F_2 + gL_2$ and $Cc_2 > S_2 + (1\text{–}h + h\alpha)\,L_2$, that is, regardless of the government's choice, the economic benefit for the construction enterprises implementing the third-party participation mechanism is less than that of not implementing the mechanism. Therefore, construction enterprises do not implement a third participation mechanism.

(2) When the factors satisfy $Cc_2 < S_2 + (1\text{–}h + h\alpha)\,L_2$ and $Cc_2 < S_2 + F_2 + gL_2$, that is, regardless of the government's choice, the cost paid by the construction for implementing the third-party participation mechanism is less

TABLE 3 | The benefit matrix between government and construction enterprises.

Construction enterprises	Government	
	Strict supervision(*y*)	Ordinary supervision(1-*year*)
Implementing the mechanism(*x*)	$-C_{c2}+S_2$, $R_2-C_{g2}-S_2$	$-C_{c2}+S_2-h(1-\alpha)L_2$, $R_2-\beta C_{g2}-S_2-h(1-\alpha)(kL_2+M_2)$
Not implementing the mechanism(1-*x*)	$-F_2-gL_2$, $R_2-Cg_2+F_2-kgL_2$	$-L_2$, $-\beta Cg_2-kL_2$

TABLE 4 | The formula of the determinant for each equilibrium point.

Equilibrium point	Det J	Tr J
(0,0)	$[S_2+L_2-h(1\text{-}\alpha)L_2-C_{c2}][R_2+(\beta-1)C_{g2}+F_2+kL_2(1-g)]$	$[S_2+L_2-h(1-\alpha)L_2-C_{c2}]+[R_2+F_2+(\beta-1)C_{g2}+kL_2(1-g)]$
(1,0)	$[C_{c2}-S_2-L_2+h(1-\alpha)L_2][(\beta-1)C_{g2}+h(1-\alpha)(kL_2+M_2)]$	$[C_{c2}-S_2-L_2+h(1-\alpha)L_2]+[(\beta-1)C_{g2}+h(1-\alpha)(kL_2+M_2]$
(0,1)	$(S_2+F_2+gL_2-C_{c2})[(1-\beta)C_{g2}-R_2-F_2-k(1-g)L_2]$	$(S_2+F_2+gL_2-C_{c2})+[-R_2-F_2+(1-\beta)C_{g2}-k(1-g)L_2]$
(1,1)	$(C_{c2}-S_2-F_2-gL_2)[(1-\beta)C_{g2}-h(1-\alpha)(kL_2+M_2)]$	$(C_{c2}-S_2-F_2-gL_2)+[(1-\beta)C_{g2}-h(1-\alpha)(kL_2+M_2)]$

than the performance delivered through the mechanism. Therefore, construction enterprises will adopt the strategy of implementing the mechanism.

(3) When $S_2 + F_2 + gL_2 < Cc_2 < S_2 + (1-h + h\alpha) L_2$ or $S_2 + (1-h + h\alpha) L_2 < Cc_2 < S_2 + F_2 + gL_2$, the benefits of construction enterprises are affected by the government. When $S_2 + F_2 + gL_2 < Cc_2 < S_2 + (1-h + h\alpha) L_2$ and $R_2 + (\beta-1) C_{g2} + F_2 + kL_2 (1-g) < 0$, enterprises will implement the mechanism, and the equilibrium point is (1,0). When $S_2 + F_2 + gL_2 < Cc_2 < S_2 + (1-h + h\alpha) L_2$ and $(\beta-1) C_{g2} + h (1-\alpha) (kL_2 + M_2) > 0$, construction enterprises will not implement the mechanism, and the equilibrium point is (0,1). When $S_2 + (1-h+ h\alpha) L_2 < Cc_2 < S_2 + F_2 + gL_2$ and the government's decision making remains unchanged, the enterprise's decision making is the reverse.

(4) For the government, when the factors satisfy the condition $R_2 + (\beta-1) C_{g2} + F_2 + kL_2 (1-g) < 0$, regardless of the strategy adopted by construction enterprises, the cost saved by ordinary government supervision is greater than the performance delivered through strict supervision; therefore, the government adopts an ordinary supervision strategy.

(5) When the factors satisfy the condition $(\beta-1) C_{g2} + h (1-\alpha) (kL_2 + M_2) > 0$, it means that regardless of the construction enterprises' strategy, the cost of strict supervision by the government is less than the cost of accidents, and thus the government chooses a strict supervision strategy.

(6) When $(\beta-1) C_{g2} + h (1-\alpha) (kL_2 + M_2) < 0 < R_2 + (\beta-1) C_{g2} + F_2 + kL_2 (1-g)$, government's strategy is determined by the decision making of construction enterprises. When $C_{c2} > S_2 + F_2 + gL_2$ and $C_{c2} > S_2 + (1-h + h\alpha) L_2$, the government will choose strict supervision; when $C_{c2} < S_2 + F_2 + gL_2$ and $C_{c2} < S_2 + (1-h + h\alpha) L_2$, the government will choose ordinary supervision.

(7) When $S_2 + (1-h + h\alpha) L_2 > C_{c2} > S_2 + F_2 + gL_2$ and $(\beta-1) C_{g2} + h (1-\alpha) (kL_2 + M_2) < 0 < R_2 + (\beta-1) C_{g2} + F_2 + kL_2 (1-g)$, the decision-making of the two participants in the game cannot be determined, and the strategies of both sides influence each other. In this case, the equilibrium points are (1,0), (0,1) and (x^*, y^*). The equilibrium points depend on the changes in x^* and y^*, which are related to the factors S_2, L_2, C_{C2}, and F_2.

SIMULATION AND ANALYSIS

To describe the stability of behavioral strategies more intuitively, this section uses numerical simulation to analyze the factors influencing the implementation of the two supervision mechanisms by enterprises in different scenarios, and validates the effectiveness of the two supervision mechanisms in improving supervision efficiency, which helps motivate construction enterprises to introduce appropriate safety supervision mechanisms.

Results and Analysis for Scenario 1

To better reflect the actual situation of the project construction stage, this study drew lessons from some references and investigated some construction projects, and the necessary data and materials were collected, as shown in **Table 5**. Both the initial probabilities x and y of the government and construction enterprises adopting the positive supervision strategy were assumed to be 0.5 in the simulation. Moreover, the effectiveness of improving supervision efficiency and the influencing factors of implementing the enterprise entity responsibility mechanism were analyzed.

To verify the effectiveness of the implementation of enterprise entity responsibility mechanisms in improving the supervision efficiency, it was assumed that the implementation of the mechanism of construction enterprises is reflected by the value of C_{c1}; the larger the value of C_{c1}, the more effective is the mechanism of the enterprises. Based on the values of the supervision cost, C_{c1} was set to 0.8, 1, 1.2, and 1.5, respectively. The MATLAB software was used for the numerical simulation analysis of the evolutionary game process of the government, as shown in **Figure 2**.

As shown in the figure above, as the value of C_{c1} continues to increase, the time t taken for the system to stabilize decreases; that is, the greater the degree of implementation of the main responsibility mechanism of the enterprise is, the faster the game system stabilizes. At this point, strict government supervision can achieve the maximum benefit, indicating that the implementation of the mechanism by construction enterprises has a positive effect on optimizing the government's safety supervision.

With other factors constant, we studied the impact of F_1, S_1, and C_{c1} on enterprises that implemented enterprise entity responsibility mechanisms. F_1 was set as 0.5, 0.7, 0.8, 0.9; S_1 was set as 0.5; 1, 1.3, 1.5. and C_{c1} was set as 0.8, 1, 1.2, 1.5. A numerical simulation analysis of the evolutionary game process is shown in **Figure 3**.

As shown in **Figure 3**, the values of F_1, S_1, and C_{c1} have an impact on enterprises' strategies. When other factors remain constant, with the increase in F_1, the rate of construction enterprises that tend to use the enterprise entity responsibility mechanism increases, and the time t taken for the system to stabilize becomes shorter. The only change is the speed at which the steady state is reached; the final steady state will remain constant. When F_1 reaches a certain level, increasing penalties have little impact on promoting enterprises to implement the enterprise entity responsibility mechanism. However, the time t taken for the system to stabilize does not decrease with increasing S_1. Therefore, the continuous increase of S_1 will not promote the implementation of the mechanism; therefore, S_1 should be kept at an appropriate level. As C_{c1} increases, the time taken for enterprises to stabilize increases, indicating that the cost spent by enterprises inhibits the introduction of the mechanism.

Results and Analysis for Scenario 2

The data in Scenario 2 were summarized and averaged, as shown in **Table 6**. Both the initial probabilities x and y of the government and construction enterprises adopting the positive supervision strategy were assumed to be 0.5. The effectiveness of improving the supervision efficiency and the influencing factors of implementing the third-party mechanism were analyzed.

TABLE 5 | The parameter values.

Parameter	C_{g1}	R_1	M_1	C_{c1}	S_1	F_1	L_1	g	h	β	k
Values	0.5	1.5	1.2	1	0.5	0.7	1.5	0.6	0.4	0.5	1

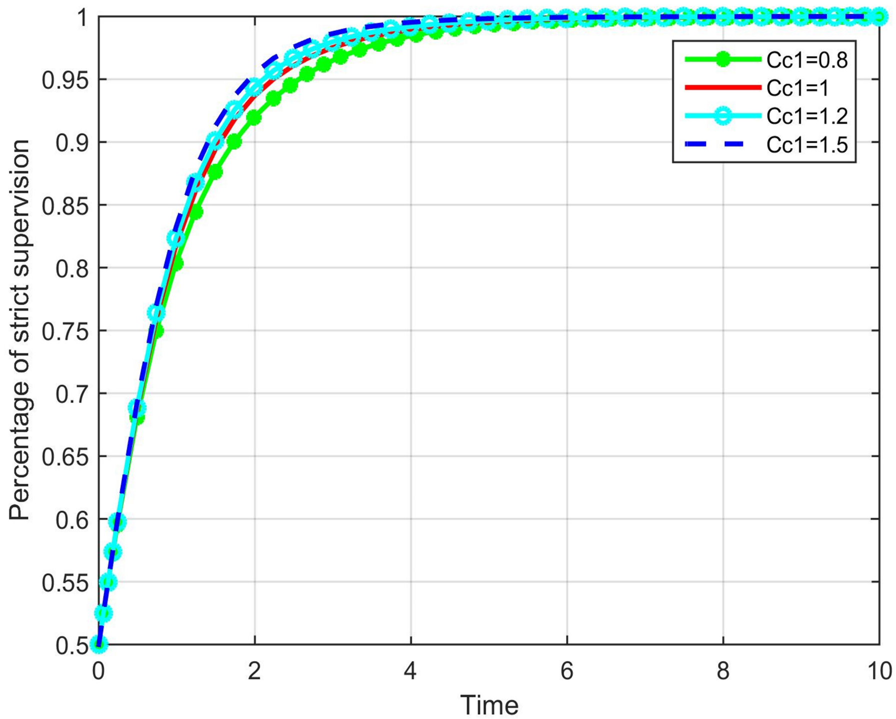

FIGURE 2 | The impact of C_{c1} on the evolution trend of government strict super.

Considering that the third-party supervision institutions do not always supervise the construction enterprises, nor can they always find unsafe behaviors of front-line workers, α is used in this model to represent the probability that the third-party supervision institutions discover and correct unsafe behaviors of enterprises; $0 < \alpha < 1$, the larger the value of α, the more effective the third-party participation mechanism of the enterprise is. The impact of the mechanism on the evolutionary results of government will be discussed. In the numerical simulation, we set α as 0.3, 0.5, 0.7, 0.9. A numerical simulation analysis of the evolutionary game process is shown in **Figure 4**.

As shown in **Figure 4**, as the value of α continues to increase, the time t taken for the system to reach a stable state of strict supervision also increases; that is, the greater the degree of implementation of the third-party participation mechanism of the enterprises, the slower the game system reaches a stable state. This shows that the relationship of the third-party supervision with government supervision is that of a substitute; the greater the supervision intensity, the smaller the supervision intensity of the government. $\alpha = 0.9$ means that the intensity of third-party supervision is so great that the government can change the existing supervision intensity. Without considering the damage to the government's reputation, the government will choose ordinary supervision because the third-party supervision replaces their supervision responsibilities.

The impact of penalties F_2, subsidies S_2, and the cost C_{c2} on the evolutionary results of construction enterprises are discussed below. The value of F_2 was set as 0.5, 0.7, 0.8, 0.9; S_2 was set as 0.5, 0.8, 1, and 1.3; and C_{c2} was set as 1, 1.5, 2, 2.5. A numerical simulation analysis of the evolutionary game process is shown in **Figure 5**.

As shown in **Figure 5**, the values of F_2, S_2, and C_{c2} affect the construction enterprises' strategy. With a continuous increase in F_2, the time t for the system to reach the stable state decreases, which indicates that the greater the penalty, the more the construction enterprises tend to choose the third-party participation mechanism. **Figure 5** shows that the probability of introducing third-party participation is sensitive to the subsidies S_2 and the cost C_{c2}, and an increase in government subsidies will encourage enterprises to introduce the third-party participation mechanism. When the cost is smaller than the threshold value, the probability of introducing the third-party participation mechanism converges to one. When the cost is greater than the threshold value, the probability converges to zero, and the convergence speed decreases with the decrease in cost. This indicates that the implementation of the mechanisms is most

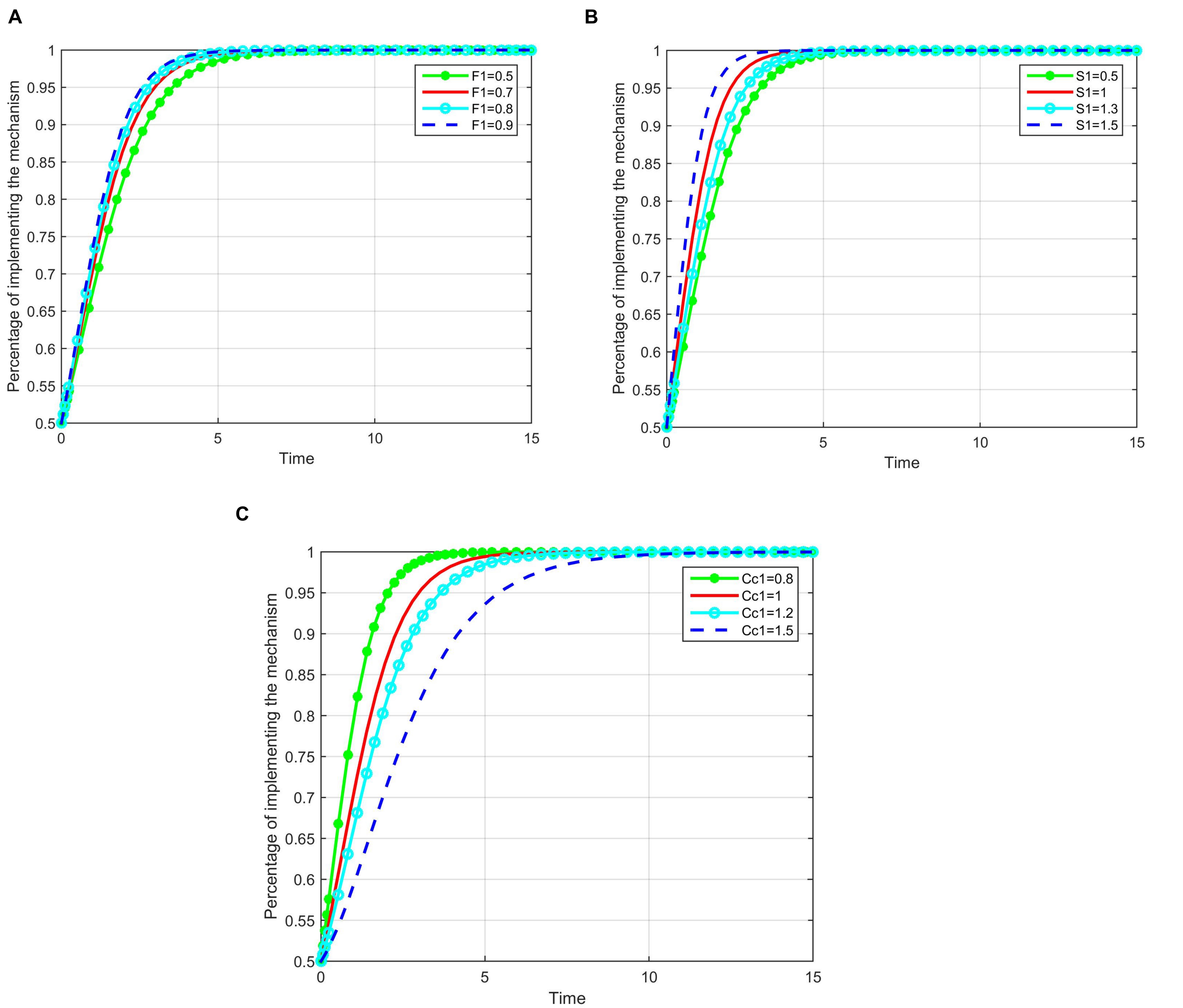

FIGURE 3 | The impact of fine, subsidy and cost on implementing the first mechanism. **(A)** The impact of fine on implementing the first mechanism. **(B)** The impact of subsidy on implementing the first mechanism. **(C)** The impact of cost on implementing the first mechanism.

TABLE 6 | The parameter values.

Parameter	C_{g2}	R_2	M_2	C_{c2}	S_2	F_2	L_2	g	h	β	k
Values	0.5	1.8	1	1.5	0.8	0.5	1	0.6	0.4	0.5	1

sensitive to the cost C_{c2}, which restrains the enterprises from introducing a third-party participation mechanism.

DISCUSSION

Main Findings

Based on the analysis in this study, different equilibrium points were obtained for the two scenarios. Through numerical simulations, we validated and compared the effectiveness of the two mechanisms in improving the supervision efficiency and discussed the factors influencing the ideal equilibrium conditions in each scenario. The main findings of this study are as follows:

The enterprise entity mechanism is an effective approach for promoting the efficiency of government supervision; by introducing this mechanism, enterprises can share the responsibility of government supervision while minimizing the probability of accidents, reducing the government cost of sharing accident risks, and maximizing the government's interests. Therefore, construction enterprises should improve their security crisis awareness and strengthen their internal management to achieve self-improvement. The decision by the enterprises to

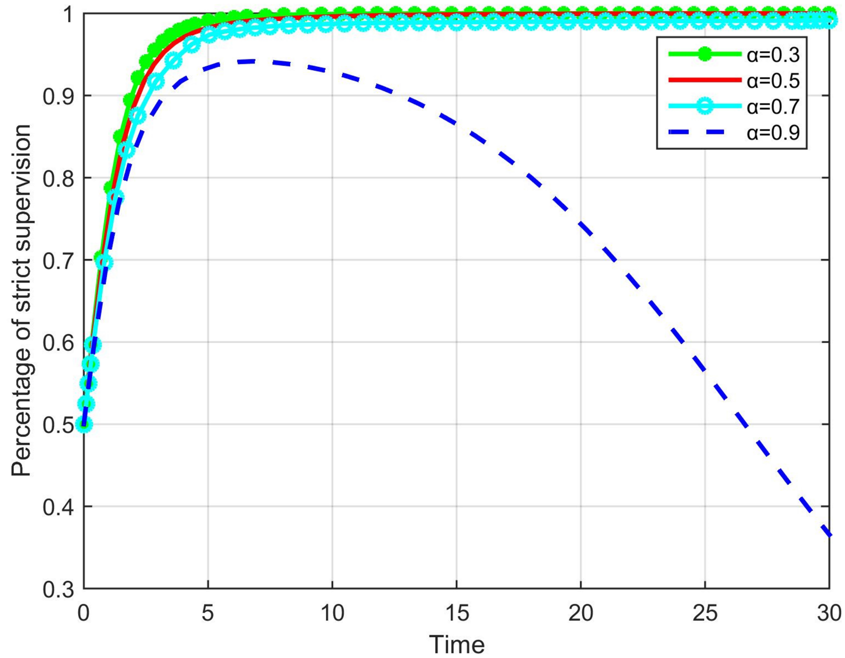

FIGURE 4 | The impact of *a* on the evolution trend of government strict supervision.

introduce the mechanism is mainly affected by the cost spent by the enterprises, which restrains the introduction of the mechanism. Concurrently, subsidies and penalties obtained by enterprises also have an impact on whether or not the mechanism is introduced. However, when the mechanism reaches a certain level, the effect of penalties is not obvious, and more subsidies are not always working better, which gives rise to the need for the government formulating policies to ensure that both penalties and subsidies reach the appropriate level.

The third-party participation mechanism has a positive effect on government supervision and can promote ordinary government supervision. In this condition, the government can accomplish its intended regulatory purposes with fewer resources, which improves the efficiency of government supervision. The effects of multiple managerial factors on the introduction of the mechanism, including punishment cost, subsidies, and supervision cost, are examined. The subsidies and cost for construction enterprises are the decisive factors that decide whether or not the enterprises undertake the mechanism. Enterprises are less sensitive to fines relative to the subsidies and costs. On the one hand, as the introduction of the mechanism is a measure and management requiring high investment costs, whether it is invested or not often has a strong inverse relationship with the profit of a project. On the other hand, compared with the enterprise entity responsibility mechanism, the punishment of enterprises not introducing the third-party participation mechanism is lower. As long as there is no accident in the project, no matter how big the danger is, it is difficult to effectively punish the enterprises. Therefore, enterprises are willing to take risks with a fluke mentality for the sake of profit. Therefore, it is suggested to (1) give full control to the multiparty synergistic effect of third-party institutions, enterprises, institutions, and research institutes; (2) innovate the cooperative governance mechanism; and (3) construct an effective mechanism of joint supervision and collaborative governance. Moreover, the government should increase subsidies to strengthen the introduction of third-party regulatory mechanisms for companies.

The third-party participation mechanism is a faster way to ensure that the system reaches a stable state and plays the most significant role in government supervision. This phenomenon aligns with actual situations. On the one hand, the third-party participation can attract professional and technical personnel engaged in quality and safety supervision to give full control to these professional and technical personnel. On the other hand, the participation of third-party institutions can provide correct and effective institutional information for the government by virtue of their working environment advantages and compensate for the information asymmetry between the government supervision departments and construction enterprises.

Theoretical Implications

First, herein, a solution is provided for the deficiencies of the existing government's supervision mode and the construction safety supervision system in China by establishing a type of synergistic and complementary safety supervision mechanism. In this study, construction enterprises not only played the role of safety producers but also safety supervisors, and the blended supervision mechanism integrating the government's passive supervision and enterprises' active supervision are introduced. This mechanism was found to effectively promote government supervision by reducing the government supervision cost and

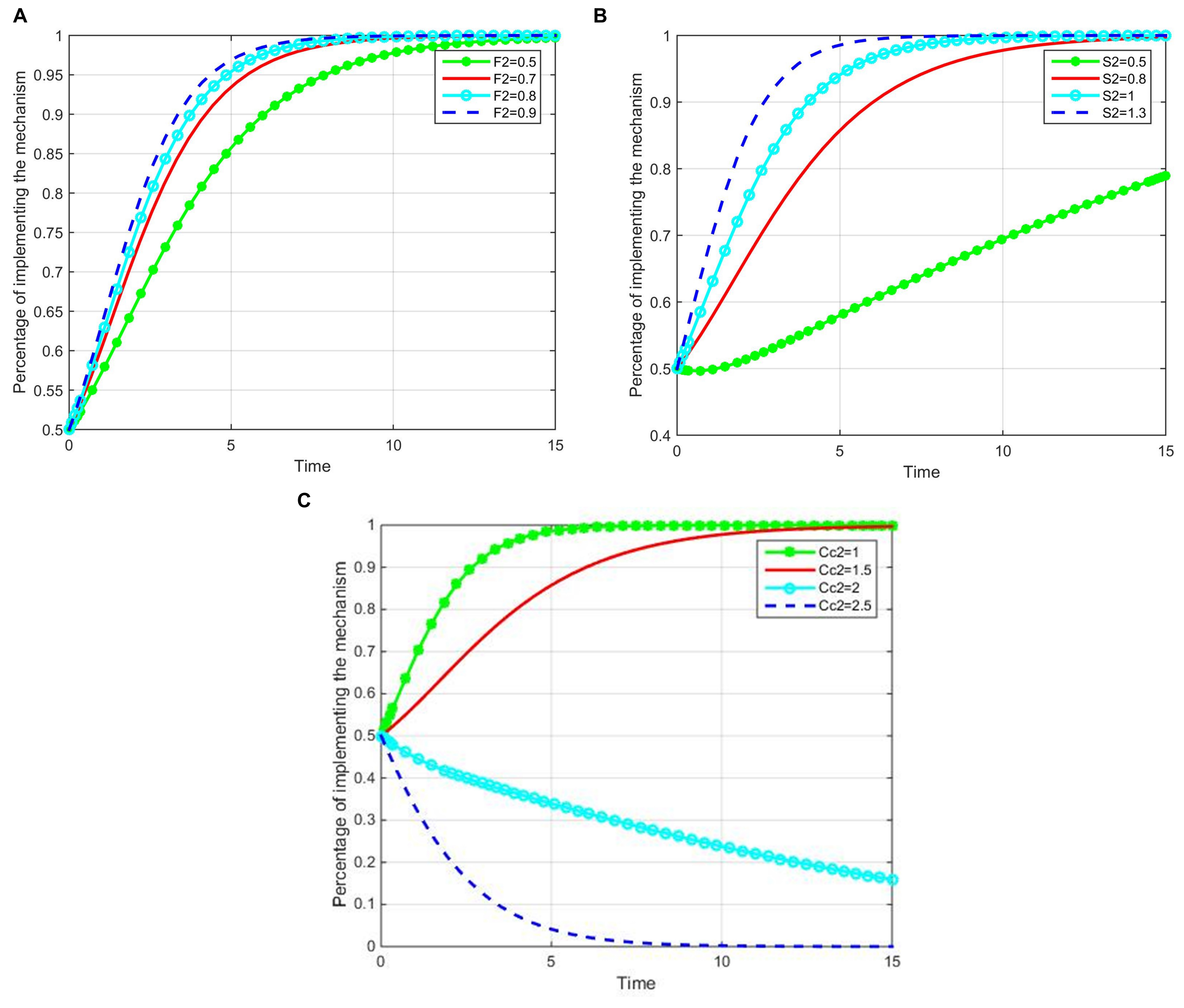

FIGURE 5 | The impact of fine, subsidy and cost on implementing the second mechanism. **(A)** The impact of fine on implementing the second mechanism. **(B)** The impact of subsidy on implementing the second mechanism. **(C)** The impact of cost on implementing the second mechanism.

accident rates. This is a pragmatic alternative to traditional government safety supervision, which enriches the theoretical system of construction safety management. The advantages of the synergistic and complementary mechanisms were given, the validity of the proposed mechanism was tested, and the analysis of the application results highlighted the advantages of the mode and provided the basis for popularization and application.

Second, this study contributes to the literature in construction safety supervision by offering a better understanding of how interactions between the government and enterprises affect the government's strict supervision. To abstract the practical problems in a rational way, we develop stylized evolutionary game models as a simplified version of reality, which outlines the decision-making interactions of the government and construction enterprises and the implementation of enterprises' active supervision mechanisms in different situations. The models excavate the decision logic behind the safety supervision behaviors of enterprises and government, reveal the root cause of the problems existing in the government, and explain how blended supervision achieves effective supervision outcomes. Our proposed research models undoubtedly provide a coherent framework as a first step toward improving the traditional "vertical supervision" mode. In addition to the construction safety supervision, this model can be used to demonstrate the supervision mechanisms of other industries.

Finally, as per the results, the proposed penalty–reward scenario was found to balance the interests of the government and construction enterprises; thereby, meeting the requirement of active supervision by construction enterprises. The study quantitatively analyzes the feasibility and effectiveness of enterprise entity responsibility and third-party participation and helps to deepen the understanding of the role of construction enterprises and third parties in construction safety supervision. The simulation illustrates the effectiveness and identifies the factors influencing the implementation of the two mechanisms, which will provide useful insights for the government to formulate more scientific and reasonable incentive policies and then have a certain reference value for the realization of active enterprise supervision and accident reduction goals.

Practical Implications

First, this study provides two alternative mechanisms for the effective supervision of the government. The new mechanisms optimize the path of government supervision, strengthen the role of a third-party in the supervision of construction safety, which shares the government's supervisory responsibility, supplement for the plight of insufficient government safety supervision force and low technical level of the hierarchical supervision. On the other hand, it also responds to national policies. Moreover, the third-party participation mechanism proposed provides enterprises with more professional engineering project safety monitoring and management services and timely supervision, urges the implementation of all parties responsible for the construction process, rectifies the problems and safety risks existing in safety management, and curbs the occurrence of safety accidents.

Second, the blended mechanism established in this study helps to restrict the insufficient safety behavior of enterprises, improve the consciousness and initiatives of enterprises which will lead to a safer working environment on construction sites, improve the efficiency of government supervision and play a vital role in reducing the occurrence of accidents. The enterprise entity responsibility mechanism proposed in this paper promotes enterprises to have a stable social environment and a good development environment which cannot only effectively reduce the economic losses caused by safety accidents, but also create a good social image for enterprises, so that enterprises can obtain social and economic benefits of the dual protection.

Finally, the analysis of the influencing factors that affect the introduction of the two mechanisms guides the government to regulate and supervise the behavior of the responsible subjects. This paper analyzes the root of the problems existing in the government supervision and actively explores the countermeasures and concrete measures to improve the government supervision of construction safety. The government can promote the implementation of enterprise supervision mechanisms by reducing supervision costs, appropriately increasing punishments, and establishing effective incentive mechanisms which balance government safety supervision and enterprise self-management and have a great significance in improving the efficiency of safety supervision and ensuring safe production.

Limitations and Future Research

Our research comes with certain limitations. The model established in this study only considers the economic losses resulting from safety accidents. As construction safety supervision is complex, the non-economic losses caused by the social environmental losses and psychological trauma are often difficult to be quantified and thus neglected to a certain extent in this study. Therefore, future research should consider these non-economic losses.

CONCLUSION

This study used an evolutionary game model to describe the decision-making interactions between the government and construction enterprises under the enterprise entity responsibility and third-party participation mechanisms. In addition, a series of simulation experiments were conducted to illustrate the factors influencing the implementation of the mechanisms. The principal conclusions of this study are as follows: First, the implementation of these two mechanisms positively affects government supervision. Second, the third-party participation mechanism has a better supervision effect than the implementation of the enterprise entity mechanism. Finally, the implementation of the two mechanisms is influenced by punishment, subsidy, and cost, and it has different sensitivities to three influencing factors that guide the government to regulate and supervise the behavior of responsible subjects. The study provides a theoretical framework for exploring the optimization mechanism of the government, which restricts enterprises' insufficient safety behavior and improves the efficiency of government supervision.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.861828/full#supplementary-material

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Study on Influencing Factors of Construction Workers' Unsafe Behavior Based on Text Mining

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The unsafe behavior of construction workers is the key cause of safety accidents. The accident investigation report contains rich experience and lessons, which can be used to prevent and reduce the occurrence of safety accidents. In order to draw lessons from the accident and realize knowledge sharing and reuse, this paper uses text mining technology to analyze the data of 500 construction accident investigation reports in Shenzhen, China. Firstly, a Latent Dirichlet Allocation (LDA) topic model is used to identify the unsafe behavior of construction workers and its influencing factors. Then, with the help of Social Network Analysis, the importance of influencing factors and the relationship between them are identified. The results show that weak safety awareness, operating regulations, supervision dereliction of duty, equipment resources, and inadequate supervision of the construction party are the key and important factors. It is also found that there are correlations between weak safety awareness and supervision dereliction of duty, between equipment resources and poor construction environment, between organization and coordination and inadequate supervision of the construction party, and between operating regulations and hidden dangers investigation. This study not only helps to improve the theoretical system in the field of construction workers' unsafe behavior but also helps managers to find the key control direction of construction safety, so as to effectively curb unsafe behavior of construction workers and improve the level of safety management.

Keywords: text mining, unsafe behavior, influencing factors, construction workers, topic model, network analysis

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INTRODUCTION

Future prospects of the global construction industry continue to be promising. Despite the coronavirus epidemic in 2019, the global investment in energy efficiency in the construction industry has reached an unprecedented 11.4% in 2020, increasing from the United States $165 billion in 2019 to about United States $184 billion (IEA, 2021). In China, with the continuous acceleration of urbanization in recent years, the construction industry has achieved unprecedented development. In 2020, the total added value of the construction industry was 7,299.6 billion Yuan, an increase of 3.5% over the previous year (National Bureau of Statistics of China, 2021). The rapid development of the construction industry has not only greatly promoted the growth of the national economy but also promoted the social labor and employment. However, the construction industry has the characteristics of a long construction cycle, complex working environment, and strong personnel mobility. It is a typical industry with a high incidence of safety accidents (Ji et al., 2021). Taking the production safety accidents of housing and municipal engineering as an example, the latest statistics of national engineering quality and safety supervision information platform of the Ministry of Housing and Urban-Rural Development of the People's Republic of China show that in 2021, the number of production safety accidents of housing and municipal engineering in China has reached to 721, with 803 deaths, an increase in 29 accidents and 8 deaths over the previous year, all of which have increased to varying degrees. Frequent construction safety accidents have not only brought huge economic losses but also caused a strong negative social impact, which has seriously affected the high-quality development of the construction industry. Therefore, the control and prevention of construction production safety accidents have attracted much national attention.

Construction production workers are front line personnel of construction projects. They are not only the direct victims of safety accidents but also their unsafe behavior is the key cause of construction safety accidents (Yu et al., 2017). Studies have shown that more than 80% of safety production accidents in the construction industry are closely related to the unsafe behavior of construction workers (Yang et al., 2021). Therefore, from the key element of "human" in the construction system as the starting point, it is very necessary to accurately identify the influencing factors of construction workers' unsafe behavior and explore the interaction between various factors, so as to reduce or avoid unsafe behavior of construction workers and control the occurrence of safety accidents.

At present, academia pays extensive attention to the influencing factors of construction workers' unsafe behavior. Scholars mainly analyze the influencing factors of construction workers' unsafe behavior from following four aspects: human, material, management, and environment. For example, psychological capital (Eid et al., 2012), physiology (Yang et al., 2021), safety awareness and attitude (Mohajeri et al., 2021; Liang et al., 2022), and work experience (Alizadeh et al., 2015; Rey-Merchán et al., 2021) are human factors; personal protective equipment (Amiri et al., 2014) and construction equipment (Castillo-Rosa et al., 2017) are material factors; safety promotion policy (Man et al., 2021), safety training (Man et al., 2021), safety atmosphere (Liao et al., 2014), safety supervision (Fang et al., 2015), safety management, and safety culture (Wang et al., 2016; Asilian-Mahabadi et al., 2018) are management factors; and working environment (Harsini et al., 2021) and social environment (Aven and Renn, 2009; Ma et al., 2021) are environmental factors. However, these studies only focus on the explicit analysis of the influencing factors of construction workers' unsafe behavior, and few studies have focused on the implicit correlation analysis between the influencing factors. At the same time, due to the limitations of the development of tools and means, the utilization of data is not sufficient. With the rapid development of Natural Language Processing (NLP), unstructured building document data can also be transformed into structured information through NLP to realize the automatic analysis of tacit knowledge in the content of construction documents, so as to realize efficient risk management (Zhang et al., 2019; Baker et al., 2020; Wu et al., 2022).

At present, the degree of information disclosure on Chinese government websites at all levels has been continuously improved, and the information module in key areas has provided a large number of construction safety accident investigation reports that contain construction safety accident case information. As China's Special Economic Zone, national economic center city and international city, Shenzhen, China, has a leading position in the disclosure of government website information in the country. According to the Blue Book "China government transparency index report" issued by the Chinese Academy of Social Sciences in recent years, since 2017, the transparency index of Shenzhen municipal government has ranked first, third, and second among the larger municipal governments, especially in 2018, 2019, and 2020. The information disclosure level of the Shenzhen municipal government website is high, and its key area information disclosure module provides a large number of work safety investigation reports. The accident investigation report is a legal document that reflects the real situation of the accident and puts forward handling opinions in the accident investigation (State Council of the PRC, 2007). The report gives an objective and true description of the process and causes of the accident, which provides an objective basis for the safety research of construction accidents. Through the analysis of the accident investigation reports, researchers can obtain the authoritative data related to the accidents, systematically analyze the unstructured data, and correlate the various factors related to construction safety, so as to identify the potential causes of construction workers' unsafe behavior.

Text mining is a process of extracting valuable information or knowledge from a large number of text data. The methods used in text mining include information extraction, topic tracking, summarization, categorization, clustering, concept linkage, and information visualization (Gupta and Lehal, 2009). The Latent Dirichlet Allocation (LDA) model is a topic model widely used in the field of text mining (Blei et al., 2003). It can effectively extract implicit topics from large-scale documents and corpora. The model is particularly ideal for long text topic mining (Jin et al., 2010; Chou et al., 2017) and has a good adaptability in topic discovery (Zhu et al., 2016), topic evolution (Zhu et al., 2016; Xie et al., 2020), and topic tracking (Yeh et al., 2016; Zhang et al., 2017). Social Network Analysis is a quantitative analysis tool evolved from network theory and integrated with mathematical methods and graph theory (Scott, 1988). Compared with other research methods, it can not only reflect the position of individuals in the whole but can also show the interdependence between individuals (Serrat, 2017). This method can use large-scale network text data mining to obtain virtual relational structure data and has good plasticity in information dissemination and content interaction (Dunne, 2012; Smith, 2013).

In view of this, this paper selects 500 construction production accident investigation reports in Shenzhen, China from 2017 to 2021 as data samples, uses the LDA model to identify the influencing factors of construction workers' unsafe behavior, and further explores the importance of influencing factors and the correlation between factors by using Social Network Analysis technology. The purpose of the study was to provide a basis for standardizing the operation behavior of construction workers, so as to reduce the occurrence of construction workers' unsafe behavior and the incidence of construction safety accidents.

This study has the following contributions: first, text mining technology is used to analyze the influencing factors of construction workers' unsafe behavior, which provides a new idea for the study of scientific management of construction safety in the era of big data. Second, the in-depth study on the influencing factors of construction workers' unsafe behavior not only helps managers to trace the root causes of unsafe behavior but also expands the existing literature in the field of construction workers' unsafe behavior.

METHODOLOGY

Overview of Text Mining Model Framework

The process of text mining includes text preprocessing, structured data, data analysis, result visualization, knowledge discovery, and other steps. The text mining model of influencing factors of construction workers' unsafe behavior, which is constructed based on the text mining process, is shown in **Figure 1**. The model takes the construction safety accident investigation report as the text mining corpus. Firstly, an LDA topic model was used to mine the topics of construction workers' unsafe behavior and its influencing factors. Then, on this basis, Social Network Analysis was used to construct the topic co-occurrence network of construction workers' unsafe behavior and its influencing factors, so as to identify the importance and correlation of the influencing factors.

Topic Model of Construction Workers' Unsafe Behavior and Its Influencing Factors

The accident causing theory points out that the movement of people and things is carried out in a certain environment, and the unsafe behavior of people should be combined with other factors (unsafe state of things, environment, etc.) (Hopkins, 2001). In the accident report, the process and causes of the accident are described in detail, objectively and truly, and the accident safety is systematically and comprehensively analyzed from the aspects of human, material, environment, and management. **Table 1** classifies some accident reports in terms of unsafe behavior and human, material, environmental, and management factors (Amiri et al., 2014; Li et al., 2015; Castillo-Rosa et al., 2017; Qiao et al., 2018; Harsini et al., 2021; Malakoutikhah et al., 2021; Man et al., 2021; Yang et al., 2021). Therefore, the construction accident investigation report can become an important basis for the analysis of construction workers' unsafe behavior and its influencing factors.

In view of the relatively long text of the accident investigation report, this paper has used the classic LDA topic model to mine construction workers' unsafe behavior and its influencing factors. The basic assumption of the LDA model is that each document is composed of a mixture of topics with a certain probability, and each topic is also composed of a mixture of feature words with a certain probability, so as to form a three-layer Bayesian probability model of "document topic feature words."

The LDA topic model needs to preset the number of topics, Blei et al. (2003) used confusion to determine the optimal number of topics K. Confusion degree is a commonly used evaluation index in the statistical language model. It refers to the reciprocal of the geometric mean of the similarity of each sentence contained in the corpus. The generalization ability of the model increases with the decrease of confusion degree. The calculation formula of confusion is:

$$Perplexity = \exp\{-\frac{\sum_{\mathrm{d}=1}^{M}\log p(w_d)}{\sum_{d=1}^{M} N_d}\} \quad (1)$$

Where, $p(w_d)$ refers to the probability of each word in the test set and N_d represents the total number of all words in the test set. The lower confusion score reveals the higher prediction ability of the model.

Topic Relationship Model of Construction Workers' Unsafe Behavior and Its Influencing Factors

The theory of trajectory intersection between man and machine is a theory of accident causes, which points out that the intersection of human trajectory and object trajectory will constitute an accident. In many cases, people and things are mutually causal, and sometimes the unsafe state of things will also induce people's unsafe behavior (Zhai, 2013). Although the LDA topic model can help to identify the topic of text, it is difficult to identify the relationship between topics in fine-grained by topic mining alone. A social network is a collection of social actors as nodes and their relationships (Freeman, 2004). The actor is the topic, and relationship refers to the number of times that two topics appear together in the text. The introduction of Social Network Analysis can clearly show the relationship network between topics and provide support for the analysis of the importance of topic words, network status, and related words. Therefore, based on the above analysis results of the LDA topic model, this paper introduces Social Network Analysis to identify the core influencing factors of construction workers' unsafe behavior and the relationship between influencing factors.

Firstly, the topic co-occurrence matrix is constructed. Summarize the subject words generated by the LDA model and build a co-occurrence network.

$$T = \begin{bmatrix} a_{11} & \dots & a_{1\mathrm{i}} \\ \vdots & \ddots & \vdots \\ a_{i1} & \dots & a_{ii} \end{bmatrix}$$

Where, the element a_{ii} on the diagonal of the subject co-occurrence matrix is 0; the element $a_{ik}(0<i<k)$ on the non-diagonal line is the number of times two topics appear in the same text. The greater the value, the stronger the correlation between the two topics.

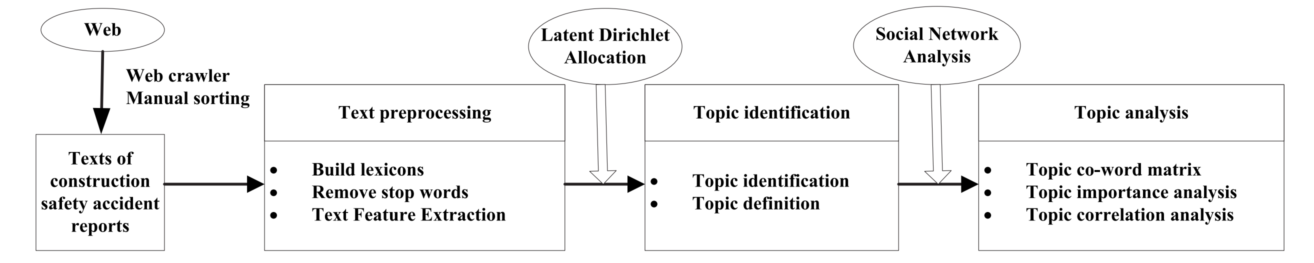

FIGURE 1 | The framework of the text mining model.

Secondly, it measures the importance of the topic. Degree centrality emphasizes the individual value of a node and measures the importance of the node in the whole network. The higher the value, the more nodes related to the point, the more they are in the center of the network, the more resources they occupy, and it can also reflect the control effect of the point on the whole network. The measure of degree centrality usually uses indicators, such as degree centrality and relative degree centrality.

Degree centrality is a measure of the differentiation of network nodes, and its calculation formula is:

$$\mathrm{C}_D(n_i) = d(n_i) \tag{2}$$

The relative degree centrality is the ratio of the actual degree to the maximum possible degree, and its calculation formula is:

$$C_D^* = \frac{d(n_i)}{\mathrm{n}-1} \tag{3}$$

In Equations 2, 3, $\mathrm{C}_D(n_i)$ represents the absolute centrality of node $_\mathrm{i}$, C_D^* represents the relative centrality of node $_\mathrm{i}$, $_\mathrm{n}$represents the number of nodes, and $d(n_i)$ represents the number of direct connections between node i and other nodes.

Finally, it identifies the relevance of the topic. Co-cohesive subgroup analysis is an important method in Social Network Analysis. Its purpose is to reveal the actual or potential relationship between social actors. When the relationship between some actors in the network is so close that they are combined into a sub-group, such a group is a cohesive subgroup. This paper uses the convergence of iterated correlations (CONCOR) method in UCINET software to analyze the influencing factors of construction workers' unsafe behavior and then identifies the correlation between the influencing factors.

DATA ANALYSIS AND RESULTS

Data Material Collection

The safety accident investigation report of this study comes from the key information disclosure module of Futian District, Luohu District, Yantian District, Nanshan District, Baoan District, Longgang District, Longhua District, Pingshan District, Guangming District, and Dapeng New Area government website in Shenzhen, China. Firstly, this paper has designed a Python crawler program, sent an Hypertext Transfer Protocol (HTTP) request through the request module to obtain the HTML page of the accident investigation report module of 10 district government websites in Shenzhen, parsed the HTML formatted content with the beautifulsoup4 module, and obtained 1,024 information data of the investigation report, such as title, time, and content links (the deadline was 20 January 2022). On this basis, a total of 500 construction safety accident investigation reports from 2017 to 2021 were selected as the data used for text mining in this paper. The number of construction safety accident reports used for text mining in various districts of Shenzhen from 2017 to 2021 is shown in **Table 2**.

Due to the long length of the safety accident investigation report, in order to reduce the impact of phrases unrelated to the

TABLE 1 | Analysis of accident statistical items.

Items	Report description (part)	References
Unsafe behavior	• Construction workers enter the dangerous area of construction for risky work • Failing to wear labor protection articles as required during operation	Qiao et al., 2018
Human factors	• Weak safety awareness, violation of the company's safety operation management regulations • Older, poor physical condition, suffering from arteriosclerosis, fatty liver, cervical, thoracic and lumbar spine and other diseases	Man et al., 2021; Yang et al., 2021
Material factors	• The trampled self-made horse stool does not meet the safety regulations • Failing to distribute labor protection articles to workers as required	Amiri et al., 2014; Castillo-Rosa et al., 2017
Environmental factors	• The elevator derrick has not taken such sealing measures as compartment hard protection (formwork and scaffold board closed) and soft protection (bag net closed) • No obvious safety warning signs have been set at the edge of the foundation pit of the bearing platform of the brick matrix foundation	Harsini et al., 2021; Malakoutikhah et al., 2021
Management factors	• Failure to carry out safety education and training for construction personnel • Failure to supervise and urge the implementation of construction safety management	Li et al., 2015; Man et al., 2021

TABLE 2 | Statistics of the number of texts in each district of Shenzhen from 2017 to 2021.

No.	District	Numbers of texts	No.	District	Numbers of texts
1	Futian	35	6	Longgang	99
2	Luohu	22	7	Longhua	79
3	Yantian	14	8	Pingshan	26
4	Nanshan	47	9	Guangming	46
5	Bao'an	119	10	Dapeng New Area	13

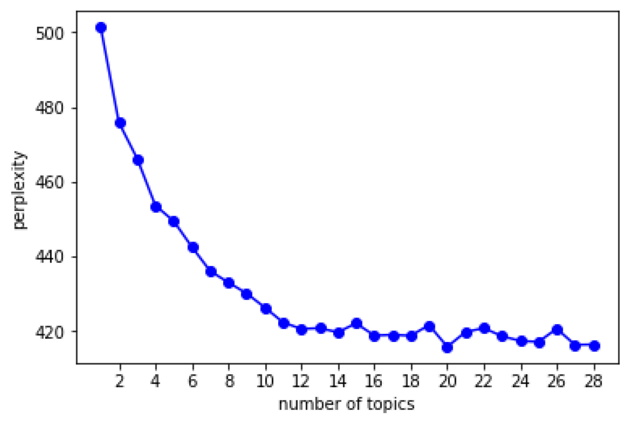

FIGURE 2 | Topic confusion value diagram.

study of construction safety workers' behavior and its influencing factors on the excavation results, only the contents of "accident process," "accident cause," and "responsibility determination" in the investigation report were selected as the corpus of text excavation. Manually revised the contents and formats of these reports and summarized them into a TXT text file. Each investigation report is a line in the text, a total of 500 lines of data, forming a corpus to be mined.

Data Preprocessing

Firstly, the text mining corpus was segmented. In order to improve the efficiency of word segmentation and ensure the accuracy and integrity of word segmentation, this paper has adopted the stop word list of Harbin Institute of Technology, Baidu stop word list, and the stop word library of machine dictionary Intelligent Laboratory of Sichuan University, and on this basis, it has used those useless high-frequency words that were less helpful to the interpretation of the results, such as "limited liability company," "unit," "Shenzhen," and others joined the stop word dictionary to build a user-defined stop word dictionary. This paper has used the jieba library of Python language to complete the word segmentation of the text mining corpus. Then, a text mining corpus was constructed to form a "document word" matrix. Since the LDA model uses a bag of words (BOWs) to generate a word frequency vector (Zhong et al., 2020), this paper has used CountVectorizer function in the sklearn library to realize the "document word" matrix.

TABLE 3 | Topic extraction results of construction workers' unsafe behavior and its influencing factors.

No.	Keywords	Behavior /influencing factors	Topic description
1	Supervision, project, responsibility, matters involved, performance, inspection, person in charge, liability	Management factors	Inadequate supervision of the construction party (SF1)
2	Hoisting, crane, steel wire rope, ground, use, fracture, falling, working at height	Material factors	Equipment resources (MF1)
3	Implement, responsibility, operation, inspection, violation, operating procedures, hazards, management systems	Management factors	Operating regulations (SF2)
4	Safety, management, awareness, use, labor, incident, inspection, no	Human factors	Weak safety awareness (HF1)
5	Performance, inspection, supervision, overall, no, problem, inspect, responsibility	Management factors	Supervision dereliction of duty (SF3)
6	Demolition, wall, bottom, method, use, labor, excavation, violation	Unsafe behavior	Construction depend on experience (B1)
7	Protective equipment, failure to, wear, use, scaffold, safety belt, performance, violation	Unsafe behavior	Protective equipment not worn (B2)
8	Live, wire, conductor, exposed, leakage, current, temporary, wiring	Environmental factors	Poor construction environment (EF1)
9	Organization, coordination, implementation, operation process, requirements, performance, failure, command	Management factors	Organization and coordination (SF4)
10	Movement, guardrail, climbing, instability, extrusion, get over, process, adventure	Unsafe behavior	Risk taking behavior (B3)
11	Qualification, have, contract awarding, acquisition, conditions, construction team, individual, illegal	Human factors	Construction qualification (HF2)
12	Discovery, troubleshooting, deficiency, hidden danger, analysis, dangerous, implementation,arrangement	Management factors	Hidden dangers investigation (SF5)

Latent Dirichlet Allocation Topic Model Analysis

The LDA topic model will generate a "topic word" matrix and a "document topic" matrix with a certain probability according to the "document word matrix", so as to screen out some topics. This paper has used Python language, sklearn library, and pyLDAvis library for topic generation and visualization.

Determination of Topic Quantity

This paper has mainly made exploratory analysis based on the LDA model and has not set the expected results according to general cognition. Therefore, the confusion degree method was used to determine the number of topics, as shown in **Figure 2**.

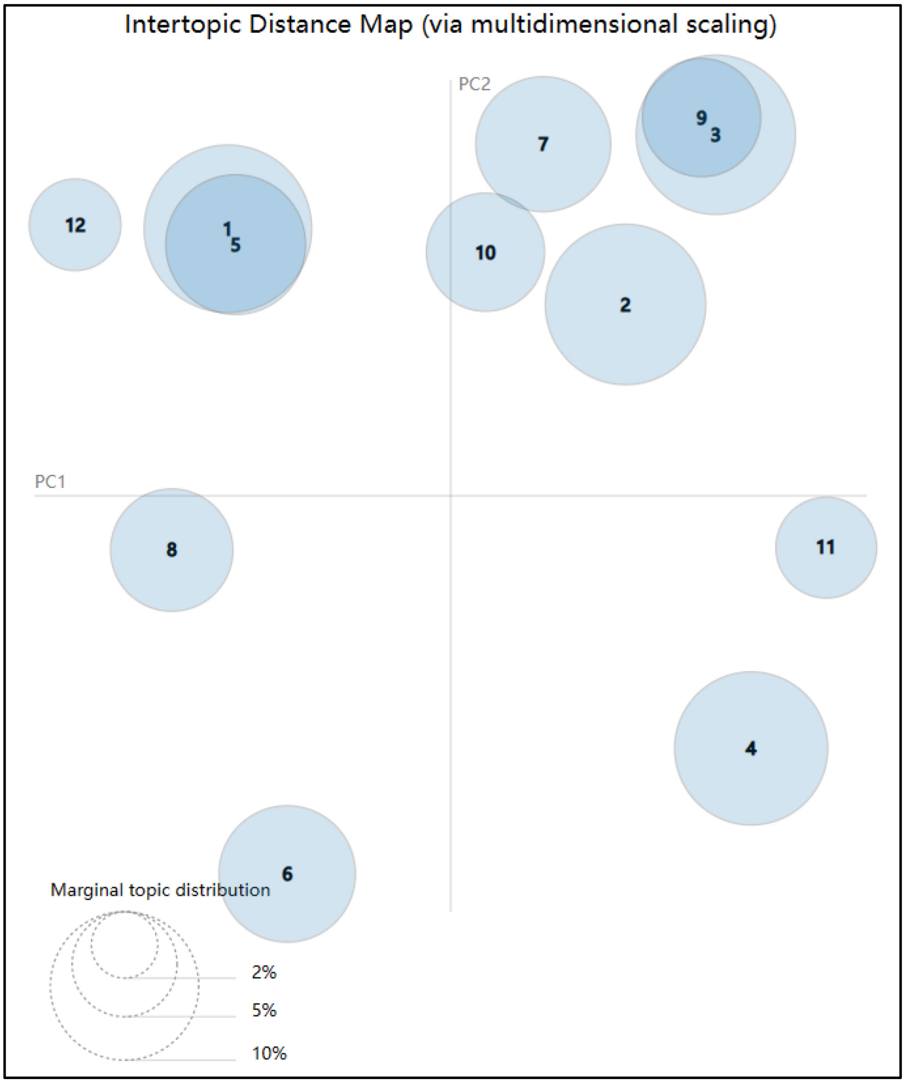

FIGURE 3 | Topic visualization.

TABLE 4 | Topic co-occurrence matrix.

	B1	B2	B3	HF1	HF2	SF1	SF2	SF3	SF4	SF5	MF1	EF1
B1	0	51	68	156	81	92	78	54	16	36	52	17
B2	51	0	121	168	36	87	65	76	57	25	45	27
B3	68	121	0	147	89	78	81	89	79	17	36	21
HF1	156	168	147	0	18	16	96	20	31	29	23	19
HF2	81	36	89	18	0	43	36	19	12	45	16	43
SF1	92	87	78	16	43	0	15	21	53	18	32	31
SF2	78	65	81	96	36	15	0	101	19	13	85	54
SF3	54	76	89	20	19	21	101	0	14	51	75	84
SF4	16	57	79	31	12	53	19	14	0	45	67	36
SF5	36	20	17	29	45	18	13	51	45	0	103	56
MF1	52	45	36	23	16	32	85	75	67	103	0	12
EF1	17	27	21	19	43	31	54	84	36	56	12	0

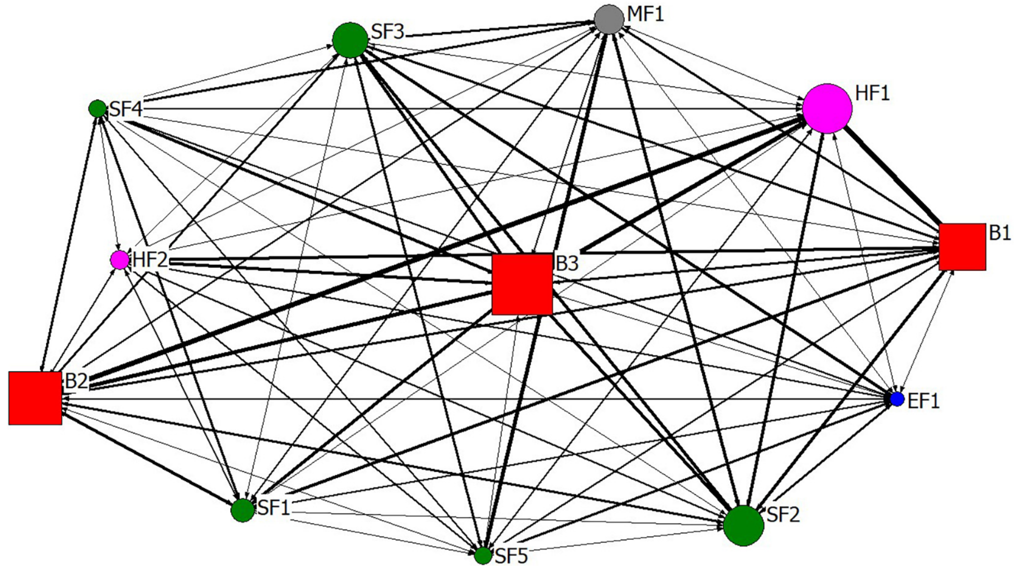

FIGURE 4 | Co-occurrence network of construction workers' unsafe behavior and its influencing factors.

As can be seen from **Figure 2**, with the increasing number of topics, the degree of confusion decreases rapidly and tends to be flat when the number of topics is 12. According to Equation 1, the lower the degree of confusion a model has, the stronger the representation ability of the model. However, in the LDA model, the more the number of topics, the lower the degree of confusion. In order to avoid over fitting caused by taking the confusion degree as the index, Blei et al. (2003) used the confusion degree subject number curve to measure the model representation ability. When the curve tends to be flat, it shows that the marginal effect of increasing the number of topics is very small. Take the inflection point as the number of topics, and there is no need to increase the number of topics excessively. Therefore, the final number of topics was 12.

Topic Description and Visualization

In this paper, the Latent Dirichlet Allocation function of the sklearn library was used to train the LDA model, and the topic extraction of construction workers' unsafe behavior and its influencing factors was carried out on the text mining corpus. Where, the number of topics K was set to 12, α was set to 1/K, β is set to 0.01, and the number of iterations was 1,000.

Because there are many feature words extracted by the LDA model and too many topic feature words are difficult to be directly used in the practical analysis, this study has selected the top 8 words as topic representatives and then carried out topic feature recognition and induction. According to the topic, characteristic words found by the LDA model and combined with the analysis of accident statistical items in **Table 1**, the labels of these 12 topics are manually defined and finally summarized in **Table 3**.

From the extracted topics, it can be seen that the calculation results of the LDA model include construction workers' unsafe behavior and its influencing factors. Finally, the pyLDAvis library is used to visualize the extracted topics, and the visualization results are shown in **Figure 3**.

TABLE 5 | Point centrality score of influencing factors of construction workers' unsafe behavior.

No.	Factor	Degree	NrmDegree	Share
1	HF1	723.000	39.123	0.104
2	SF2	643.000	34.794	0.092
3	SF3	604.000	32.684	0.087
4	MF1	546.000	29.545	0.078
5	SF1	486.000	26.299	0.070
6	HF2	438.000	23.701	0.063
7	SF5	433.000	23.431	0.062
8	SF4	429.000	23.214	0.061
9	EF1	400.000	21.645	0.057

TABLE 6 | Identification of influencing factors of construction workers' unsafe behavior.

Grade	Influencing factors
Key factor	Weak safety awareness (HF1)
	Operating regulations (SF2)
	Supervision dereliction of duty (SF3)
Important factor	Equipment resources (MF1)
	Inadequate supervision of the construction party (SF1)
Secondary factor	Construction qualification (HF2)
	Hidden dangers investigation (SF5)
	Organization and coordination (SF4)
General factor	Poor construction environment (EF1)

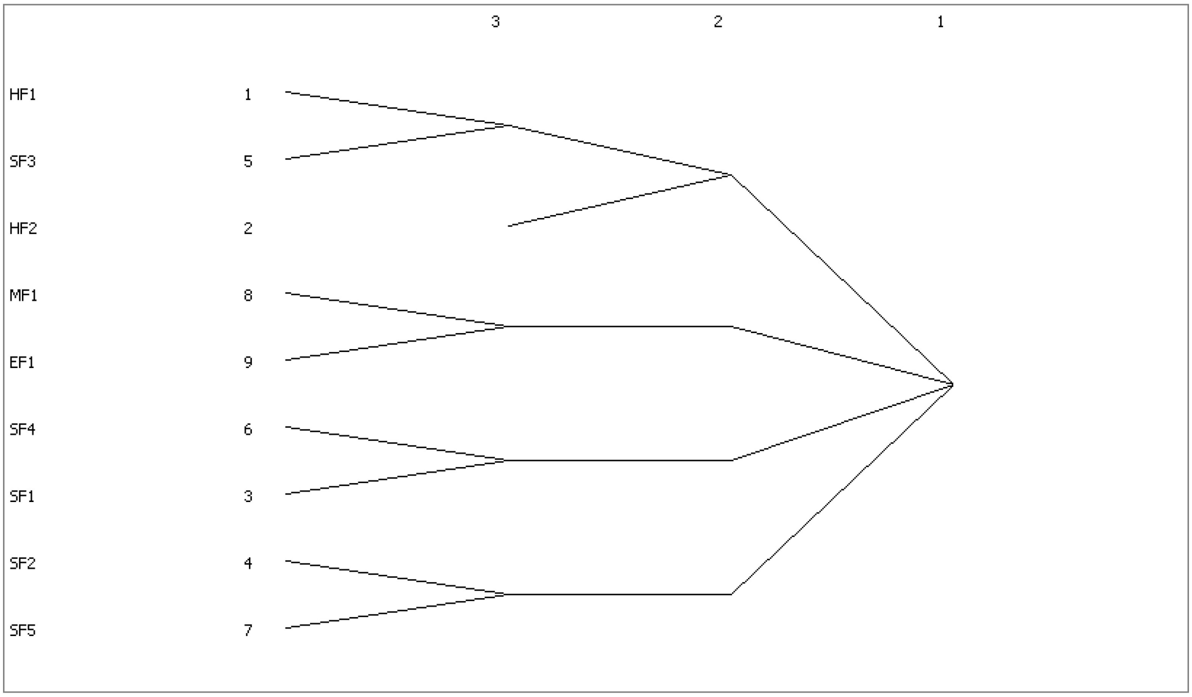

FIGURE 5 | Network aggregation subgroup tree of influencing factors of construction workers' unsafe behavior.

Different circles in **Figure 3** represent different topics, and the numbers in the circles correspond to the topic serial number in **Table 3**. The distance between circles is used to describe the distance between topics, that is, to express the proximity between topics. There is overlap in the two circles, indicating that the characteristic words in the two topics are crossed. For example, the overlapping area of the circle between Topics 1 and 5 is relatively large, mainly because Topic 1 is related to the adverse supervision of the construction party and Topic 5 is related to the dereliction of duty of the supervisor. Both topics have common characteristic words, such as "inspection" and "responsibility."

Topic Social Network Analysis

Co-occurrence Network of Construction Workers' Unsafe Behavior and Its Influencing Factors

In this part, firstly, the characteristic words of LDA were sorted and summarized according to **Table 3**, and the characteristic words under the same subject were used as the subject characteristic identification to construct the subject co-occurrence matrix, as shown in **Table 4**. In the co-occurrence matrix, the diagonal element is 0, and the non-diagonal element is the number of times that two topics appear simultaneously in 500 accident investigation report texts. For example, B1 (construction depends on experience) and HF1 (weak safety awareness) appeared 156 times at the same time.

Based on the topic co-occurrence matrix, this paper has used UCINET software to draw the co-occurrence network diagram of unsafe behavior of construction workers and its influencing factors, as shown in **Figure 4**. In **Figure 4**, different nodes of the network represent different topics, in which the square represents the topic of construction workers' unsafe behavior, the circle represents the topic of influencing factors of unsafe behavior, and the co-occurrence relationship of each topic is represented by the connection of nodes. The size of the circle (square) represents the importance of the topic in the co-occurrence network, and the size between the two nodes represents the closeness of the two topics in the co-occurrence network. For example, among all circles, circle HF1 (weak safety awareness) has the largest circle, indicating that the topic is the most important of all influencing factor topics. Among all node connections, HF1 (weak safety awareness) has the thickest connection with blocks B1 (Construction depend on experience) and B2 (protective equipment not worn), indicating that this influencing factor is most closely related to the unsafe behavior, such as construction depends on experience and protective equipment not worn.

Analysis on the Importance of Unsafe Construction Workers' Influencing Factors

Point centrality is a key index to reveal the importance of nodes in social networks. If the node is in the center of the network, its point centrality value will be the highest. The importance of the influencing factors of construction workers' unsafe behavior can be revealed by point to the center analysis of the influencing factors of construction workers' unsafe behavior. **Table 5** shows the score and ranking of point centrality of influencing factors of construction workers' unsafe behavior, where Degree represents absolute centrality, NrmDegree represents standardized centrality, and Share represents the ratio of the centrality of each node to total centrality. According to the degree value, HF1 (weak safety awareness) ranks first among all influencing factors, indicating that this topic has the most important impact on the unsafe behavior of construction workers.

According to the share value, this paper uses the following standards to classify the influencing factors of construction workers' unsafe behavior: Share $\geq$ 0.08 is the key factor; 0.07 $\leq$ Share $<$ 0.08 is an important factor; the factor of 0.07 $\leq$ Share $\leq$ 0.06 is the secondary factor; the factors with Share less than 0.06 are general factors. See **Table 6** for details.

Correlation Identification of Influencing Factors of Construction Workers' Unsafe Behavior

A condensed subgroup describes a subset with relatively strong, direct, close, and frequent connections. The cohesive subgroup analysis shows that the substructure of the influencing factors network of construction workers' unsafe behavior is closely related. As can be seen from **Figure 5** that node HF2 alone constitutes a cohesive subgroup, while nodes HF1 (weak safety awareness) and SF3 (supervision dereliction of duty), MF1 (equipment resources) and EF1 (poor construction environment), SF4 (organization and coordination) and SF1 (inadequate supervision of the construction party), SF2 (operating regulations), and SF5 (hidden dangers investigation) have a strong trust relationship, and several small groups have been formed.

CONCLUSION AND FUTURE WORK

Based on the accident investigation reports on the websites of the people's governments of various districts in Shenzhen, China from 2017 to 2021, this paper uses the LDA topic model to identify construction workers' unsafe behavior and its influencing factors from the accident reports and constructs the topic social relationship network to identify and analyze the importance of the influencing factors of construction workers' unsafe behavior and the correlation between the influencing factors. The main conclusions are as follows:

(1) With the help of an LDA topic model, three kinds of construction workers' unsafe behavior and nine influencing factors are identified from the total accident report of construction. The three kinds of construction workers' unsafe behavior is a construction that depends on experience, protective equipment not being worn and risk-taking behavior. The nine influencing factors of construction workers' unsafe behavior are inadequate supervision of the construction party, equipment resources, operating regulations, weak safety awareness, supervision dereliction of duty, poor construction environment, organization and coordination, construction qualification, and hidden dangers investigation. Among them, weak safety awareness and construction qualification are human factors; equipment resources are material factors; inadequate supervision of the construction party, operating regulations, supervision dereliction of duty, organization and coordination, and hidden dangers investigation are management factors; the poor construction environment is environmental factors.

(2) The topic co-occurrence network is used to show the co-occurrence relationship between construction workers' unsafe behavior and its influencing factors, and the nine influencing factors are divided into four levels, i.e., key factors, important factors, secondary factors, and general factors, according to the centrality. Among them, weak safety awareness, operating regulations, supervision dereliction of duty, equipment resources, and inadequate supervision of the construction party are the key and important factors, and the managers should attach great importance to them and focus on control.

(3) Through the agglomerative subgroup analysis of the influencing factors of construction workers' unsafe behavior, we can see the internal relationship of the influencing factors. According to **Figure 5**, it can be found that there are correlations between weak safety awareness and supervision dereliction of duty, between equipment resources and poor construction environment, between organization and coordination and inadequate supervision of the construction party, and between operating regulations and hidden dangers investigation. It can be seen that the effects of some influencing factors on construction workers' unsafe behavior are superimposed. Managers should systematically analyze them and put forward targeted measures.

The conclusions of this paper have important theoretical and practical significance. First, this paper uses text mining technology to explore the influencing factors of construction workers' unsafe behavior, which provides a new idea for the study of scientific management of construction safety in the era of big data. Second, this study not only finds the key and important factors of construction workers' unsafe behavior but also finds the implicit correlation of the influencing factors, thus broadening the research boundary of the influencing factors of construction workers' unsafe behavior. Third, the findings of this paper will help regulators to systematically examine the motivations of construction workers' unsafe behavior and then formulate targeted measures to reduce construction workers' unsafe behavior and incidence of construction safety accidents.

The limitations of this paper need to be improved in future research. Since this study only uses the accident investigation reports in Shenzhen, China as the data sample, the research data are limited and have a certain regionality, and the generalizability of the conclusions of this study cannot be guaranteed. In the follow-up study, the number and regional scope of samples can be appropriately expanded. In addition, this study only identifies the influencing factors of workers' unsafe behavior and their importance and relevance by using text mining technology. On this basis, subsequent studies can further explore the impact path of various influencing factors on construction workers' unsafe behavior.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/participants or patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

PL contributed to methodology, data analysis, and writing. YH contributed to conception and methodology. ZL contributed to writing and checking. All authors contributed to the article and approved the submitted version.

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Formation Mechanism and Dynamic Evolution Laws About Unsafe Behavior of New Generation of Construction Workers Based on China's Construction Industry: Application of Grounded Theory and System Dynamics

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Construction workers' unsafe behavior is a major cause of safety accidents and injuries, therefore, a profound understanding of the formation process and evolution laws about construction workers' unsafe behavior is conducive to taking measures to prevent incidents. At present, the new generation of construction workers (NGCWs) born after 1980 are gradually becoming the main force at construction sites in China. Given that generational differences of construction workers can cause the discrepancies in their thoughts and attitudes when engaging in safety-related activities, this study aims to investigate the formation mechanism and dynamic evolution laws about NGCWs' unsafe behavior based on the context of China's construction industry. From the perspective of behavior motivation, in-depth semi-structured interviews with 18 NGCWs and 7 grassroots managers were conducted, and data analysis followed a three-step coding process based on grounded theory. Through continuous comparison, abstraction and analysis, the stimulus-organism-response theory was introduced and expanded to construct a three-stage formation mechanism model. On this basis, the causal diagram and stock flow diagram were developed based on system dynamics principles to reflect the dynamic feedback relationships of the factors in the static formation mechanism model, and simulation was carried out using Vensim PLE software. The results show that three types of internal needs and three types of external incentives stimulate corresponding motivations for NGCWs' unsafe behavior. Two types of individual factors, five types of situational factors and behavior result play an influencing role in the decision-making process of externalizing motivation into behavior. Under the synergistic effect of multiple factors, the level of unsafe behavior displays a downward trend, and the rate of decrease is slow first and then fast. Furthermore, among individual factors and situational factors, safety awareness and safety management system have the most significant effect on the level of unsafe behavior, while situational factors play a more obvious role. The findings can provide theoretical support and practical references to China's construction companies and government departments for the purpose of improving NGCWs' unsafe behavior.

Keywords: unsafe behavior, formation mechanism, dynamic evolution laws, new generation of construction workers, behavior motivation, grounded theory, system dynamics

INTRODUCTION

Due to high accident and casualty rates, the construction industry has long been regarded as one of the most dangerous industries (Im et al., 2009; Abbas et al., 2018; Hasanzadeh et al., 2019). China's construction industry is likewise in a precarious state in terms of safety. From 2010 to 2019, around 7275 construction workers died in workplace accidents, with an average of 1.99 deaths per day (Xu and Xu, 2021). Furthermore, since 2015, the number of safety accidents and fatalities in housing and municipal construction has shown an increasing trend year by year (Zhang J. et al., 2020). The occurrence of accidents can have a detrimental influence on workers, their families, the organizations and even the whole society (Peng et al., 2015). It is clear that the safety production situation in this sector in China is still severe and complicated, and the level of safety management needs to be improved further. Unsafe behavior is a major cause of injuries at construction sites, which leads to approximately 80%–90% of all accidents (Han and Lee, 2013). Construction workers, as the ultimate executors of construction projects and the primary victims of accident injuries, are fundamental to behavioral safety and the most critical aspect in safety management (Liu et al., 2020). Therefore, reducing the prevalence of construction workers' unsafe behavior remains an effective way to carry out incident prevention.

As a typical labor-intensive industry, the construction industry provides employment for about 220 million people worldwide, including a substantial share of migrant workers (Shepherd et al., 2021). This is especially noticeable in China. Driven by the wide urban-rural income disparity and attracted by the low requirements of job seekers' educational background and professional skills, large numbers of migrant workers have treated the construction industry as a common destination industry (Jiang et al., 2020). According to the monitoring survey report on migrant workers in 2020 released by National Bureau of Statistics of China, the construction industry accounts for 18.3% of the employment of migrant workers, second only to the manufacturing industry; in terms of age, migrant workers aged 40 and below account for 49.4% of all (National Bureau of Statistics of China, 2021). Because of *hukou* (household registration) system, more than 90% of construction workers are migrant workers (Swider, 2015). As a result, as current demand for construction labor force increases (Man et al., 2021) and the old construction workers return to their hometowns for retirement, the construction workers born after 1980 are gradually becoming the main force at construction sites (Ni et al., 2020). Previous research has revealed that workers who are younger and have less job experience are more prone to engage in unsafe behavior (Qiao et al., 2018). Younger workers, in particular, have higher occupational injury rates (Salminen, 2004; Breslin and Smith, 2005; Sámano-Ríos et al., 2019), and thus are in greater need of occupational safety and health services (Dragano et al., 2018). Additionally, numerous statistics and studies have indicated that migrant construction workers are more likely to be involved in safety accidents than native construction workers (e.g., Kim J. M. et al., 2020; Shepherd et al., 2021). In light of dual effect of times and industry, it is vital to pay more attention to the safety of young generation of construction workers in China.

In view of the key role of the post-80s migrant workers in the process of urbanization, the Chinese authorities first proposed the idea "new generation of migrant workers" in Document No. 1 of the Chinese Communist Party Central Committee and the State Council in 2010, and stressed that specific measures must be taken to solve the problem (Franceschini et al., 2016). In this manuscript, the new generation of construction workers (NGCWs) refer to workers and laborers who were born after 1980, aged 16 and above, and engaged in front-line construction work. They mainly consist of new generation of migrant workers who work in cities and registered in rural areas. Unlike their parents, NGCWs were born during a period of reform and opening up, and most of them are also the first one-child generation. A rising standard of living, an increasingly open environment, and fewer life adversities and setbacks have built their significant distinctions. NGCWs are usually better educated and have higher overall quality than the old generation (Lin and Mai, 2018). They are more concerned with quality of life and aspire to urban lifestyles (Franceschini et al., 2016; Zheng, 2021), therefore, the majority of them leave for cities and spend more time on non-agricultural activities (Zhao et al., 2018). Besides, they pursue freedom and have an adventurous spirit, but lack the capacity to cope with stress and are reluctant to suffer, presenting major features such as strong emotional oscillation, low job satisfaction, and resistance to rules and constraints (Cennamo and Gardner, 2008; Lin and Mai, 2018; Fang et al., 2020). Different generations are believed to share various personality characteristics in terms of values and preferences due to diverse upbringing circumstances. These differences pose significant challenges for organizational management, because groups with different values often vary in their workplace attitudes and behaviors (Dencker et al., 2008). According to survey statistics, 80% of occupational accidents are related to the post-80s in China (Gao et al., 2015). It is evident that traditional safety management measures have limited effect on reducing the occurrence of NGCWs' unsafe behavior (Gao et al., 2016; Ni et al., 2020). Companies and organizations should modify their practices and regulations to meet generational disparities in work values and behaviors (Wey Smola and Sutton, 2002); nevertheless, adjustments to address NGCWs' unsafe behavior are still rare in the construction industry.

To ameliorate the current situation, it is necessary to explore the causes of NGCWs' unsafe behavior. However, previous studies seem to neglect the particularity of NGCWs. Moreover, the majority of these studies only focused on the relationships between antecedents and unsafe behavior, such as emotional exhaustion (Ju et al., 2016), safety habits (Mohajeri et al., 2021), and perceived safety climate (Seo, 2005). Although these research hypotheses contribute to the establishment of theoretical models and have some theoretical significance, there are still certain limitations. On the one hand, most of these factors are not the direct cause of unsafe acts; on the other hand, the relevant antecedents derived from the exploration are more fragmented and lacking in systematization, so inevitably have the disadvantages of singularity and one-sidedness in the face of complex construction environment. Research on formation mechanism of unsafe behavior is a deepening on the basis of influencing factors, which overcomes the shortcomings of the analysis of a single factor. The formation of unsafe behavior is a relatively complicated process, and clarifying the formation mechanism of unsafe behavior assists managers and workers in making specific preparations for controlling unsafe behavior, which is of great significance to on-site management practice (Fang et al., 2016).

Unsafe behavior that leads to accidents is often intentional (Donald and Cantor, 1993), which shows that even if workers are aware of the hazardous situation, they still choose unsafe acts (Fang et al., 2016). Behavior motivation is an essential perspective for understanding the formation mechanism of unsafe behavior. It plays a vital function in determining the intensity and direction of behavior (Quested et al., 2017), which considered a direct driver of human acts. Therefore, in many fields, motivation has been recognized as a significant element in the prediction of behavior (e.g., Mattingly et al., 2012; Ha and Ng, 2015). In general, motivation, knowledge and ability are three determinants of work behavior, however, in normal work situations, whether the work can be done safely may be determined more by motivation because employees can usually acquire the pre-requisite knowledge and skills needed via selection and training (Andriessen, 1978).

In the field of safety science, current research on motivation still focuses on the measurement and examination of the influence between two variables (e.g., Panuwatwanich et al., 2017; Lim et al., 2018; Ansori et al., 2021; Mohajeri et al., 2021). Little scholarly attention has been paid to the formation mechanism of construction workers' unsafe acts from the perspective of motivation, that is, the pathway between motivation and unsafe behavior of construction workers has not been sufficiently portrayed. Additionally, generational differences caused by different social environments in which the workers grow up ought to be fully considered, however, the NGCWs with distinctive era characteristics have not received more research support in terms of their unsafe behavior. Moreover, it is necessary to explore the dynamic evolution laws about construction workers' unsafe behavior in order to intuitively analyze its changes. Therefore, this study aims to specifically analyze and portray the formation mechanism of NGCWs' unsafe behavior from the perspective of behavior motivation using grounded theory, and this process also benefits from the stimulus-organism-response (SOR) theory which can offer a suitable framework to explain how unsafe behavior occurs. Following that, the current study explores the dynamic evolution laws, developmental stages and key influencing factors of NGCWs' unsafe behavior as well. It is expected that the findings can fill the research gap, enrich the literature on construction workers' unsafe behavior and provide a new insight to improve safety performance at construction sites in China.

FORMATION MECHANISM OF NEW GENERATION OF CONSTRUCTION WORKERS' UNSAFE BEHAVIOR

Research Design

Research Method

In this study, a grounded theory approach was utilized to explore the formation mechanism of NGCWs' unsafe behavior. Grounded theory is a scientific qualitative research method, which mainly observes a phenomenon and aims to develop a theory based on the data systematically collected and analyzed (Urquhart et al., 2010). This method emphasizes the systematic data analysis program, and extracts the core concepts and categories of the original data via repeated comparison, analysis and refinement (Lyu, 2020). Moreover, it offers excellent support for abstracting and relating categories to each other through different coding processes (Goldkuhl and Cronholm, 2010). Most importantly, given the scarcity of research on the reason for NGCWs' unsafe behavior, grounded theory could provide a novel methodological design to enhance the understanding of how workers' perspectives, attitudes, and behavior are constructed in specific personal and social contexts (Narushima and Sanchez, 2014). Therefore, a three-level coding procedure (including open coding, axial coding, and selective coding) (Strauss and Corbin, 1998) was applied to analyze original data, extract key elements of the formation process and analyze the interaction mechanism, so as to make up for the defects that quantitative research is not suitable for digging deeper into the phenomenological information.

Participants

Considering that self-reports and personal impressions or observations of others' behavior are all valuable sources of information (Nübold et al., 2017), the researchers will approach and collect data from NGCWs and grassroots managers who are willing to report on themselves and someone else. On the one hand, it avoids participants to conceal themselves during the interview because of touching on sensitive topics that may bring them trouble; on the other hand, grassroots managers are more familiar with the construction sites and may be more likely to reveal how NGCWs' unsafe behavior occurs from an objective perspective. To ensure the scientific validity and high heterogeneity of data sources, this study did not restrict the workplaces and job types of the participants. Additionally, the NGCWs interviewed were limited to those born after 1980, and there was no restriction on the age of managers. Moreover, the researchers did not determine the sample size in advance, but kept collecting data. In this process, theoretical sampling strategy was employed until the theory reached saturation, i.e., no new categories and relationships emerged. Although the value of qualitative studies may depend more on the quality of the data than the size of sample (Ni et al., 2021), the number of participants in this manuscript is in line with the recommendation of 20–30 for grounded theory (Nübold et al., 2017). Ultimately, theoretical saturation was reached after conducting 25 interviews, including 18 (72%) NGCWs and 7 (28%) grassroots managers. All participants are male, and the basic information of participants is shown in **Table 1**.

Data Collection

In-depth semi-structured interviews were conducted with participants to collect the data needed. The in-depth qualitative interview is particularly suitable for grounded theory because both of them are open and oriented (Charmaz, 2006). Meanwhile, the semi-structured interview has the advantage of being two-way interactive, and it allows interviewers to flexibly adapt and add additional questions based on the answers given by the interviewees to explain in more depth how the person experienced. In particular, prompts can be given when interviewees fail to answer or deviate from the topic to ensure that the conversation can continue, which avoids the problem that individual literacy or understanding bias may affect the judgment of the questions in traditional questionnaires.

The data collection was conducted mainly in the form of phone calls and WeChat, supplemented by on-site interviews. The interview team comprised of 2–3 researchers, with one leading the interview process, one recording the relevant information in real time using a tape recorder, and another one acting as a mobile person to participate in the interview process when needed. In order to improve efficiency, the whole process was conducted around outlines which help to guide participants to fully express their opinions and viewpoints on the subjects. The questions in the outlines are based on relevant literature (e.g., Man et al., 2017), and specific outlines are presented in **Appendices A, B**. Each interview lasted approximately 50–70 min. After an interview, the collected audio data was converted into initial text data in a timely manner.

Data Analysis

Open Coding

Open coding is the process of abstracting different concepts from the original utterance data and merging concepts with similar meanings into subcategories (Lyu, 2020). The researchers imported interview data into NVivo 12.0 software for coding

TABLE 1 | Basic information of participants.

Number	Position	Age (year)	Experience (year)	Educational background	Project location
A_{01}	Construction crew	26	5	Undergraduate	Hubei
A_{02}	Project manager	49	20	High School	Fujian
A_{03}	Site supervisor	28	3	Undergraduate	Shandong
A_{04}	Safety inspector	28	4	Undergraduate	Shandong
A_{05}	Foreman	26	7	Secondary specialized school	Jiangsu
A_{06}	Safety inspector	28	5	Undergraduate	Shandong
A_{07}	Site supervisor	30	4	Undergraduate	Jiangsu
B_{01}	Worker man	30	10	Junior high school	Hebei
B_{02}	Electric welder	26	6	Secondary specialized school	Jiangsu
B_{03}	Electric welder	32	10	Secondary specialized school	Jiangsu
B_{04}	Carpenter	37	15	Junior high school	Jiangxi
B_{05}	Tower crane operator	26	6	Primary school	Anhui
B_{06}	Bricklayer	26	10	Junior high school	Hunan
B_{07}	Scaffolder	30	10	Junior high school	Jiangsu
B_{08}	Plasterer	33	10	Junior high school	Jiangxi
B_{09}	Wall and floor tiler	37	14	Junior high school	Jiangsu
B_{10}	Carpenter	31	10	Junior high school	Fujian
B_{11}	Painter	33	8	Junior high school	Jiangsu
B_{12}	Reinforcing bar worker	35	12	Junior high school	Jiangxi
B_{13}	Plasterer	28	5	Junior high school	Jiangxi
B_{14}	Scaffolder	29	7	Junior high school	Shandong
B_{15}	Tower crane operator	26	8	Secondary specialized school	Jiangsu
B_{16}	Painter	38	18	Primary school	Henan
B_{17}	Carpenter	34	10	Junior high school	Guangdong
B_{18}	Painter	29	7	Junior high school	Henan

A_i represents grassroots managers; B_j represents NGCWs.

and strictly adhered to the coding procedure. During the coding process, a line-by-line and sentence-by-sentence reading was taken to mark the information closely related to the purpose of this study, and to distill and summarize it into concepts. Following that, the connections between concepts were further explored, and concepts with interrelated meanings were grouped into subcategories. In order to avoid subjective bias, the subcategories were named by extracting the original words of the participants, but also by drawing on relevant literature for summarizing and refining. In addition, constant comparison and revision were required to identify similarities and variances among participants. In this work, 169 concepts and 28 subcategories were formed by repeated comparison, integration, and generalization. **Table 2** shows an excerpted sample of refinement and induction process of open coding, and 2–3 concepts with the highest frequency of occurrence were selected from each subcategory for display.

Axial Coding

The object of axial coding is to analyze the correlation between subcategories and further discover the categories (Zhao et al., 2020). Next, several dimensions or directions of the theory can be extracted. The researchers further analyzed the relationships of the 28 subcategories acquired by open coding, and finally obtained 16 categories. Some of the categories, subcategories as well as the connotation of subcategory are shown in **Table 3**.

Selective Coding

Selective coding is a process that revisits the source material after open coding and axial coding to unearth the core category and develops the integration of theoretical constructs (Draucker et al., 2007). The core category must be overarching and maximize the ability to encompass the findings within a broad theoretical scope (Zhang W. et al., 2020). That is, the goal of selective coding is to develop a single storyline around which everything else revolves (Zhou et al., 2015). And the conceptualization of relational form between categories makes the analytical story coherent and theorized (Charmaz, 2006). Through repeated investigation and analysis of the relationships between the categories, the researchers eventually re-clustered the 16 categories into five sub-core categories: internal needs, external incentives, situational factors, individual factors and behavior result. This storyline also emerged: NGCWs' motivations for unsafe behavior, which are stimulated by internal needs and external incentives, are the direct cause of their unsafe behavior; individual and situational factors regulate the link between motivation and behavior, and thus influence the decision-making process of externalizing motivation into behavior; unsafe behavior is closely related to safety accidents which considered a potential result, and whether or not an incident occurs may further influence the decision-making process. Based on this storyline, the core category "the formation mechanism of NGCWs' unsafe behavior" was proposed. The coding results are shown in **Table 4**.

Construction and Explanation of Formation Mechanism Model

Construction of Formation Mechanism Model

The SOR model is derived from the field of environmental psychology, and it is usually used to describe the relationship of the stimulus (S) received by the individual, the internal evaluation of the organism (O) and the response (R) produced by the individual (Mehrabian and Russell, 1974). "Stimulus" mainly refers to the surroundings that an individual encounters at a specific time (Jacoby, 2002), which may include the external environment as well as the physical and psychological internal

TABLE 2 | Subcategories and concepts developed from original interview data through open coding (excerpted sample).

Number	Subcategory	Concept	Original interview data
1	Pursuit of comfort	Laziness	A_{03} "It is common for lazy workers to fail to take the safety precautions before work."
		Discomfort	B_{03} "You know it is very hot in the summer. It's uncomfortable to wear a helmet, so sometimes I don't wear one."
2	Weak risk perception	Underestimation of accident rates	B_{01} "You think the likelihood of an accident without a helmet is so small that you think it's okay, is that right?" "Yes."
		Danger perception	B_{01} "Older workers are more experienced and have a better ability to perceive danger than we do."
		Unawareness of risks	A_{05} "First of all, the management is not in place. Second, the workers themselves are not aware of the potential risks, and the incidents at construction sites cannot be completely prevented. There is no way to deal with everything. The key is to be careful yourself."

TABLE 3 | Categories developed through axial coding and the connotation of subcategory (excerpted sample).

Category	Subcategory	The connotation of subcategory
Physiological needs	Time and effort saving	Failure to perform necessary safety operations in order to save time and increase efficiency.
	Pursuit of comfort	Failure to perform necessary safety operations in order to purse comfort.
Psychological needs	Self-esteem needs	Workers' enjoyment of performing unsafe acts to project themselves in groups; the rebellion in the face of criticism and the refusal to obey instructions due to the priority of saving face.
	Sensation seeking	A willingness to challenge oneself, the thought of risk-taking and a tendency to try unsafe acts.

TABLE 4 | Coding results.

Core category	Sub-core category	Category	Subcategory	Concept
Formation mechanism of NGCWs' unsafe behavior	Internal needs	Physiological needs	Time and effort saving	Thought of finishing work early, pursuit of efficiency, etc.
			Pursuit of comfort	Laziness, discomfort, etc.
		Psychological needs	Self-esteem needs	Pursuit of a "tough guy" image, concern for self-esteem, bravado, etc.
			Sensation seeking	Frequent risky attempts, curiosity, etc.
		Economic needs	Increase of income	Thought of making more money, thought of working more to earn more, etc.
	External incentives	Work stress	Schedule pressure	Hurry at work, schedule compression, deadline, etc.
			Leadership pressure	Leadership arrangements, fear of leadership displeasure, etc.
		Group norms	Expedient conformity	Silence of co-workers on unsafe behavior, silence of managers on unsafe behavior, etc.
			Blind conformity	Simple imitation of older workers, conformity, etc.
		Poor quality of social exchange relationships	Discord with workmates	Frequent disputes, fights, etc.
			Destructive leadership	Accusation in public, failure to deliver on promises, indifference on workers, etc.
			Weak sense of belonging	Weak relationship connection, high mobility, etc.
	Situational factors	Safety climate	Safety management commitment	Failure to lead by example, leadership non-compliance with safety regulations, profit orientation, etc.
			Workers' safety participation	Little safety communication, non-reporting of accidents, etc.
		Safety management system	Safety regulations	Inappropriate safety procedures, improper work practices, etc.
			Safety supervision	Insufficient safety inspection, failure to impose penalties, etc.
			Safety training	Explanation of safety knowledge, training of safety skills etc.
	Individual factors	Unsafe psychology	Fluke psychology	Luck, fluke, etc.
			Paralysis psychology	Empiricism, paralysis, etc.
		Safety risk perception	Weak risk perception	Underestimation of accident rates, danger perception, unawareness of risks, etc.
		Self-efficacy	High self-confidence	Thought of few hazardous situations, frequent risky attempts, etc.
		Safety awareness	Weak safety awareness	Habitual failure to wear safety equipment, low awareness of precautions, lack of awareness of the importance of safety, etc.
		Work experience	Little work experience	Lack of familiarity with the work, little experience of accidents, etc.
	Behavior decision-making		Choice of safety behavior	Choice of observation of safety rules and regulations, choice of wearing protective equipment, etc.
			Choice of unsafe behavior	Choice of not wearing a dust mask, choice of sitting on the protective railing to rest, etc.
	Behavior result	Safety accident	Accident	Occurrence of accidents, absence of accidents, lessons from accidents, etc.
	Behavior result feedback		Positive feedback	Tendency to violate regulations next time, tendency to perform unsafe acts next time, etc.
			Negative feedback	Lessons learned, tendency to wear a helmet next time, etc.

environment (Lai, 2010). "Organism" refers to the emotional and cognitive intermediary states that occur when an individual interacts with stimuli (Tang et al., 2019). According to this model, environmental factors can stimulate human emotion and cognition (Kim M. J. et al., 2020). It shows that the stimulus reinforces an individual's internal state (Eroglu et al., 2001). Finally, the individual makes behavior responses, that is, behaves in an approach or avoidance manner (Floh and Madlberger, 2013), because the reinforcements are positive or negative. The SOR model takes both objective environmental and subjective psychological factors into consideration, and it may reflect psychological states and behavior changes of individuals in response to stimuli, which is a suitable explanation for the generation of individual behavior. Therefore, this model has been widely applied to understand consumer behavior (e.g., Jacoby, 2002; Floh and Madlberger, 2013), tourism behavior (e.g., Jiang, 2022) and energy saving behavior (e.g., Tang et al., 2019). However, it has received little attention in the field of behavioral safety. The SOR theory is applicable in the present study for two reasons. First, its interpretation and understanding of complex behavior in various situations has been successfully tested by many previous studies. Second, it provides a structured theoretical framework. Based on this, the impact of the internal and external stimuli encountered by NGCWs on internal psychological state and subsequent behavior choices can be more reasonably explained. Therefore, it can offer a structured research framework as well as a solid theoretical foundation for investigating the formation process

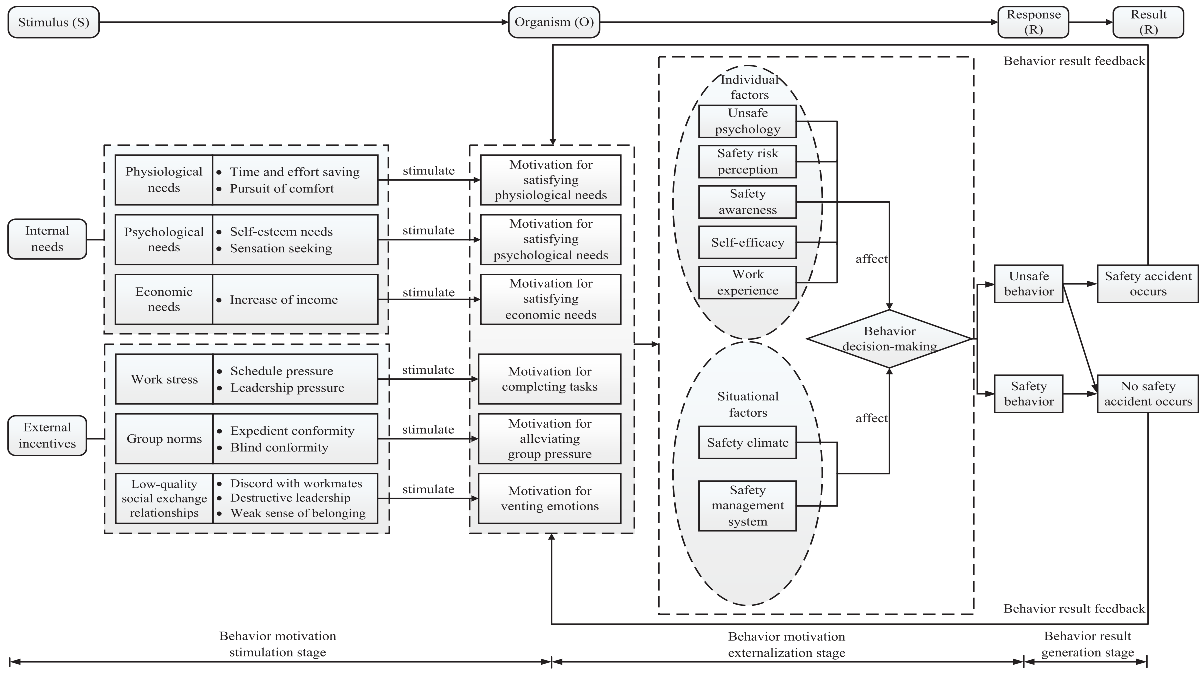

FIGURE 1 | Formation mechanism model of new generation of construction workers (NGCWs') unsafe behavior.

of NGCWs' unsafe behavior. On the basis of the coding result and the storyline, the internal needs and external incentives that stimulate corresponding motivations for the organism's (O) unsafe behavior are considered stimuli (S), and then response (R), i.e., unsafe behavior, happens. Given that the result of unsafe behavior, i.e., whether safety accident occurs, can affect the decision-making process, this manuscript introduced result (R) link to expand the SOR theory and constructed the SORR model, which fully reflects the internal logical structure of internal needs and external incentives, motivation for unsafe behavior, unsafe behavior, and behavior result. As a result, through the correspondence and integration of the expanded SORR framework and the story line, a three-stage formation mechanism model of NGCWs' unsafe behavior was eventually constructed, which is illustrated in **Figure 1**.

Explanation of Formation Mechanism Model

Behavior Motivation Externalization Stage

(1) Internal needs:

The internal need is one of the main factors that stimulate NGCWs' motivation for unsafe behavior. Many of the participants talked about unsafe behavior that they had personally experienced or heard about from the perspective of need. Saving time and effort as well as pursuit of comfort, are two prime triggers for the motivation for satisfying psychological needs. Heavy construction activities and long hours of work cause NGCWs to engage in behavior that improve efficiency and comfort, such as working at heights without safety harnesses, using human ladders to overload building materials, crossing safety guardrails, etc. The finding is consistent with Man et al. (2017), who found that saving time is the most attractive motivation for construction workers to adopt risk-taking behavior, moreover, saving energy, convenience and comfort are associated with utilitarian outcomes as well. A qualitative study by Wong et al. (2020) also confirmed that construction workers would not wear personal protective equipment (PPE) if they valued and prioritized utilitarian outcomes. Aside from physiological needs, NGCWs have a plethora of psychological needs, such as self-esteem and sensation seeking. Some grassroots managers interviewed said that NGCWs tend to perform unsafe operations because of the priority of saving face. A_{03}, for example, expressed his view, "young workers want to prove that they are 'tough guys' and they are not fear of getting hurt." A_{06} stated that, "even if you warn him that it is dangerous, he would not obey you since he may feel humiliated to admit that he was wrong." One possible explanation is that NGCWs are more eager to be recognized and respected (Giddy and Webb, 2018), besides, Choudhry and Fang (2008) also found that the need to present oneself as a "tough guy" is one of the main reasons for construction workers' unsafe behavior. Furthermore, among individual characteristics, sensation seeking refers to the need for diverse, intense and novel sensations and experiences (Zuckerman, 1979). It is directly tied to risk propensity, and people with high sensation seeking are more inclined to take risks and may suffer more harm (Hasanzadeh et al., 2020). According to the interview data, A_{03} stated that, "Some young workers work at heights without safety ropes and often sit on fall protection fences because they find it exciting." One possible reason is that the younger generation scores higher in sensation seeking, and sensation seeking decreases with aging (Butkoviæ and Bratko, 2003). In addition, NGCWs who are in their middle and young adulthood are under pressure to start a family, buy a car and a house, and educate their children. The economic need drives them to do hazardous but highly rewarding acts, and even work with illness and fatigue in exchange for higher wage payments. For example, B_{06} said, "We are definitely here to make money, and it doesn't matter if we are safe or not, so we work as fast as we can." B_{10} said, "We are paid by the quantity, and we will get more money if we work fast. After all, if you don't work, you don't get paid."

(2) External incentives:

The external incentive is the other cause of NGCWs' motivation for unsafe behavior. Pressure from the leadership and the time limit for a project make NGCWs passively complete their work tasks. Previous research has revealed the negative effects of stressful schedules and leadership pressure on safety behavior (e.g., Lipscomb et al., 2008). The interview data supports this point, for instance, B_{04} said, "Although I am very tired and want to lie down for rest after a long day work, the foreman asks me to work overtime." When asked, "Don't you think of the possibility of danger when you are not wearing safety ropes?" B_{01} said, "Yes, I know it's dangerous to fail to wear a safety rope. But I'm in a hurry, I need to catch up." Group norms are a form of submission to the herd mentality, which refers to the tendency of NGCWs to abandon the principle of compliance with safety rules and regulations under the pressure of organizational environment. In this study, group norms include both in terms of expedient conformity and blind conformity, which are manifested as compromise and passive unsafe behavior. It can be found that the motivation for alleviating group pressure often leads to the malignant infection and spread of unsafe behavior, which seriously threatens the safety production at construction sites. Several participants supported this view, for example, B_{04} said, "Everyone does this (throwing cigarette butts at no-fire zones). I'm sure nothing is wrong if everyone else does." Moreover, discord with workmates and destructive leadership make NGCWs difficult to feel support from workers and leaders. Once there is a lack of emotional connection, NGCWs are more likely to leave, and companies with high staff turnover are more prone to encounter safety problems (Jiang et al., 2015). At the same time, the high level of mobility makes it more challenging for NGCWs to develop a sense of belonging to the team and trust in their leaders and fellow workers. Over time, they may accumulate unpleasant feelings and tend to engage in violent acts to vent their emotions, which can easily lead to unsafe behavior and eventually cause serious issues (Adinyira et al., 2020).

Behavior Motivation Externalization Stage

Behavior motivation externalization stage is a decision-making process that is impacted by different elements. Based on the interview transcripts, five categories of individual factors (i.e., work experience, unsafe psychology, safety awareness, safety risk perception and self-efficacy) and two categories of situational factors (i.e., safety climate and safety management system) were uncovered.

(1) Work experience:

New generation of construction workers tend to be inexperienced and are not aware of the potential risks and hazards posed by unsafe behavior. Workers interviewed indicated that their assessment of behavior largely depended on previous work experience, and they would regard the option for unsafe acts as safe if they had not suffered negative repercussions. According to a study by Man et al. (2017), younger employees are more likely to engage in risky activities. The interview transcripts are also in accordance with the findings of Choudhry and Fang (2008) that less experienced people have a more shallow understanding of safety standards. Furthermore, grassroots managers believe that owing to a lack of work experience, NGCWs have insufficient ability to detect potential risks and to deal with crisis events. It seems difficult for NGCWs to carry out proper self-help, which may result in more severe injuries. The interview data also revealed that as workers' age and length of service rise, so would their experience with safety concerns, capacity to master safety-related regulations as well as protection abilities.

(2) Unsafe psychology:

Unsafe psychology includes fluke psychology and paralysis psychology in the present study. Fluke is a gambling mentality, which is one of the main psychological causes of violations (Fu et al., 2020). One worker interviewed said that in many cases, operations against regulations happened because NGCWs believed that the occurrence of hazards was a small probability event, and they usually assumed that these operations would not be found and punished by regulators. Moreover, one manager interviewed provided his view that paralysis psychology usually caused workers to overestimate their ability and temporary experience, which made them easy to become slack, manifesting in sloppy work, non-compliance with appropriate safety regulations and a lack of concern for the quality of work. It is clear that a lack of attention and vigilance to accidents can easily lead to paralysis (Fu et al., 2020).

(3) Safety risk perception:

Safety risk perception means further judgment or consideration of the possibility and severity of safety accident consequences (Bohm and Harris, 2010). Underestimation of safety risks is common in construction workplaces (Choudhry and Fang, 2008). In general, perceived risk vary from person to person (Shin et al., 2014). The relationship between age and risk perception has received a lot of attention (e.g., Basha and Maiti, 2013; Han et al., 2019), but specific trends have not been provided. In this study, safety risk perception substantially influenced the decision-making progress, i.e., whether NGCWs engaged in unsafe acts. The majority of NGCWs are aware of the risks involved in their work; however, the risks tend to be underestimated. The managers interviewed also indicated that NGCWs are less able to perceive hazards owing to the lack of safety understanding.

(4) Safety awareness:

Safety awareness is the underlying state of consciousness in which people notice the hazards around (Man et al., 2017), which makes people aware of which behavior foster safety (Wang et al., 2018). The majority of interviewees agreed that most unsafe behavior happens as a result of NGCWs' own weak safety awareness. For example, B_{09} said, "..., the workers' sense of danger prevention is relatively shallow around." The interview data revealed that NGCWs seem to constantly blindly pursue efficiency without regard for safety and be unable to remain alert to the potential hazards during construction production activities. Choudhry and Fang (2008) pointed out that creating safety awareness within the organization is an important duty of the management team.

(5) Self-efficacy:

According to Bandura's definition (Bandura, 1977), self-efficacy refers to NGCWs' belief in the ability to exert control over dangerous situations in the present study. This concept is considered to be a personality trait that may greatly influence individuals' choices of activities in different cases. NGCWs are more likely to perform dangerous tasks if they believe they can control the consequences of their actions, or hold the point that the mission is easy to complete. Some workers felt confident to perform dangerous operations because of dexterity and responsiveness; besides, they also reported that the match between their individual physical strength and the physical demands of the job made leaders inclined to assign them hazardous tasks, which further boosted their self-confidence. However, overconfidence may prompt people to set unrealistic goals and thus exhibit accident-related unsafe behavior (Salanova et al., 2012). According to the interview records, some unsafe acts happen owing to over-confidence in abilities, such as working at heights without safety harnesses and working with hands instead of tools.

(6) Safety climate:

Safety climate is a psychological perception that reflects employees' perceived evaluation of the organization's emphasis on safety-related issues (Fogarty and Shaw, 2010). Numerous studies have shown that employees' safety behavior is the most frequent safety performance output of group safety climate (e.g., Lu and Tsai, 2010; Brondino et al., 2012). In this study, safety climate includes safety management commitment and workers' safety participation. Employees' safety behavior can be negatively affected if managers do not follow safety rules (Fogarty and Shaw, 2010). Previous interviews support this view, for example, when asked, "Don't the managers correct you? Don't they take safety seriously?" B_{01} answered, "If he (the manager) doesn't wear it (safety helmet) himself, who will wear it?" Another manager interviewed expressed the viewpoint that when managers fail to prioritize safety inputs or even take the lead in not following safety rules, it will influence workers' decision for safety behavior. It's clear that the organization's great attachment to safety and expectations for workers to perform tasks without compromising health may effectively promote prevention of human errors. In terms of workers' safety participation, B_{12} said, "When others are working very carefully and cautiously, they do so themselves." However, researchers found that NGCWs at the construction sites did not have a high level of safety participation. According to Fang et al. (2006), employees who are older, married or support more family members may have more positive perceptions of safety climate. As workers get older, their perception of safety climate may gradually increase.

(7) Safety management system:

Safety management system helps ensure effective monitoring of the company's safety policies, procedures and practices (Gürcanli and Mungen, 2009). Most managers pointed out that without sound safety regulations, safety management would be chaotic. The response we obtained like, "Only under the constraints of regulations can the unsafe behavior of young construction workers be effectively reduced, and the safety regulation is an important factor influencing workers to make decisions about safety behavior." In addition, safety supervision is crucial to carry out accident prevention. Respondents believe that the current site safety supervision is not well implemented. For example, when asked, "The implementation of safety supervision of workers in your project is not quite in place, is that right?" B_{01} said, "Indeed, supervision is often inadequate, so that unsafe behavior often happens and cannot get immediately stopped." This is consistent with a finding of Man et al. (2017), the latter discovered that safety supervision is an effective way to reduce risk-taking behavior of construction workers. Moreover, to raise risk perception and understanding of the negative repercussions of unsafe behavior among NGCWs, safety training can impart vital safety knowledge, particularly information regarding the harmful consequences. Almost all of the NGCWs interviewed stated that they had gradually identified some hazardous operations after safety training.

Behavior Result Generation Stage

One manager noted that if nothing happened, workers would regard the choice of unsafe acts was feasible and they would continue to engage in unsafe practices. The interview transcripts and coding results validated Skinner's reinforcement theory (Skinner, 1968). This theory, which focuses on human behavior, can plausibly explain the impact of behavior outcomes on the motivation for unsafe behavior. As a stimulus, the behavior result has a reinforcing effect on individuals. People can actively adapt to stimuli and constantly adjust their behavior according to the feedback information. Skinner divides this effect into positive reinforcement and negative reinforcement. Behavior that is positively reinforced have a greater likelihood of reappearance. Negative reinforcement means that the adverse consequences of behavior weaken or block the continuation of this behavior. In the current research, if NGCWs' unsafe behavior does not result in a safety accident, it will increase the likelihood that the same unsafe behavior happens. On the contrary, if the consequences caused by unsafe behavior are more severe, such as property losses and serious injuries, it will weaken the possibility of the occurrence of unsafe behavior next time. During the construction of the formation mechanism model, the researchers considered the feedback of behavior result on motivation.

DYNAMIC EVOLUTION LAWS ABOUT NEW GENERATION OF CONSTRUCTION WORKERS' UNSAFE BEHAVIOR

Research Method

According to **Figure 1**, the formation mechanism of NGCWs' unsafe behavior is a complex dynamic system with multi-factor interactions, which requires a holistic and dynamic view. System dynamics draws on the ideas of information theory and cybernetics to improve itself, eventually becoming a discipline

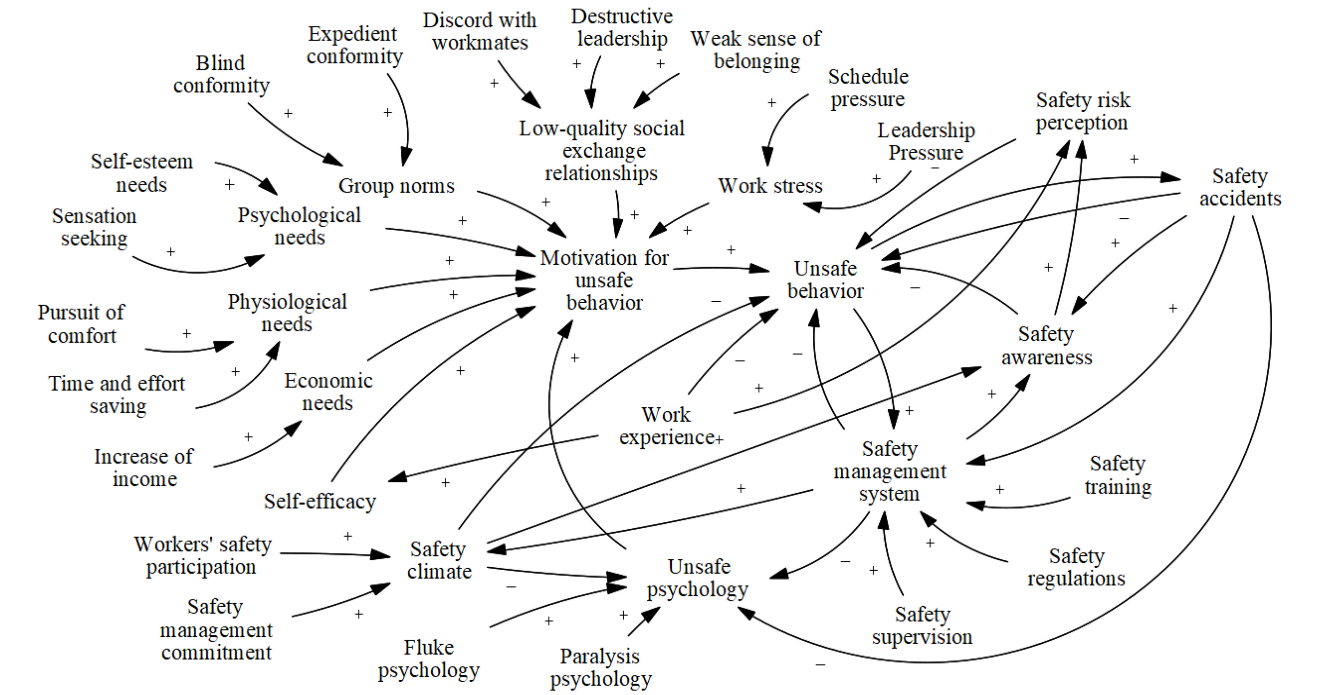

FIGURE 2 | The causal diagram.

that studies the information feedback system. It focuses on the causal relationships between variables and observes the dynamic feedback structures of the factors using computer technologies. The applicability of this method to complicated systems has led many scholars to use it to analyze safety-related behavior of construction workers (e.g., Jiang et al., 2015; Yu et al., 2019; Ma et al., 2021) and safety management issues (e.g., Mohammadi and Tavakolan, 2019; Yu et al., 2019; You et al., 2020). Previous research has demonstrated the superiority of system dynamics in improving the understanding of intricate safety systems. Therefore, from the perspective of system evolution cycle, system dynamics was applied to reveal the dynamic evolution laws about NGCWs' unsafe behavior, and then identify the key influencing factors, so as to lay the theoretical foundation for proposing relevant measures.

Construction of System Dynamics Model

Before constructing the causality diagram, on the basis of the relevant literature, interview transcripts, and the formation mechanism model, the feedback relationships of the factors in the system of NGCWs' unsafe behavior were analyzed. This process was performed through the following logic: First, motivation for unsafe behavior is the direct driver of unsafe behavior, and the link from motivation to unsafe behavior is built. Second, as shown in the formation mechanism model, internal needs and external incentives directly stimulate motivation for unsafe behavior. Thus, the links of them are built. Third, an in-depth analysis of the feedback of remaining factors, unsafe behavior and motivation for unsafe behavior is conducted to build the links of them. As a result, the causal diagram was constructed to visualize the complicated dynamic feedback of the factors, as shown in **Figure 2**, where "+" indicates positive feedback and "-" indicates negative feedback. In addition, on the basis of the causal diagram, the stock flow diagram (**Figure 3**) was established for data simulation to derive more accurate control management results. The researchers separated the categories of variables and assigned 8 state variables, 10 rate variables, 8 auxiliary variables, and 20 constants. **Table 5** lists the variable names and symbols.

System Dynamics Equations and Model Parameter Settings

According to the system dynamics principles and the logical relationships among the variables, the system dynamics equation for each variable was compiled as follows:

$$\mathbf{S_1 = INTEG\ (R_1 - R_2, initial\ value\ of\ S_1)}$$

$$\mathbf{S_2 = INTEG\ (R_3, initial\ value\ of\ S_2)}$$

Where INTEG is the integral function, indicating the value of the state variable S. Other state variable equations can be given with reference to the equations of S_1 and S_2.

$$\mathbf{R_1 = S_2 \times f_{11} + S_3 \times f_{12} + S_4 \times f_{13}}$$

Where f_{11}, f_{12}, f_{13} are the weights of S_2, S_3, S_4, and $f_{11} + f_{12} + f_{13} = 1$. Other rate variable equations can be given with reference to the equation of R_1.

$$\mathbf{A_1 = C_1 \times l_{11} + C_2 \times l_{12}}$$

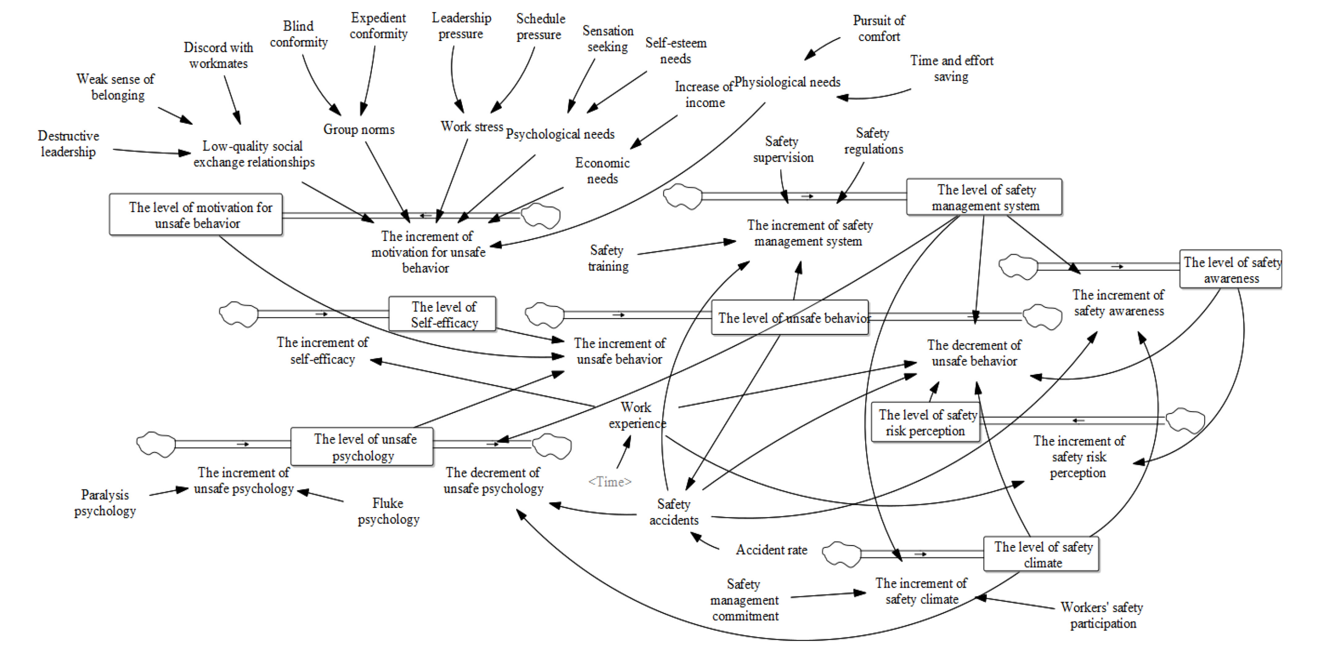

FIGURE 3 | The stock flow diagram.

TABLE 5 | Variable names and symbols.

Variable Type	Variable Name
State Variable	The level of unsafe behavior (S_1), The level of motivation for unsafe behavior (S_2), The level of self-efficacy (S_3), The level of unsafe psychology (S_4), The level of safety risk perception (S_5), The level of safety awareness (S_6), The level of safety climate (S_7), The level of safety management system (S_8)
Rate Variable	The increment of unsafe behavior (R_1), The decrement of unsafe behavior (R_2), The increment of motivation for unsafe behavior (R_3), The increment of self-efficacy (R_4), The increment of unsafe psychology (R_5), The decrement of unsafe psychology (R_6), The increment of safety risk perception (R_7), The increment of safety awareness (R_8), The increment of safety climate (R_9), The increment of safety management system (R_{10})
Auxiliary Variable	Physiological needs (A_1), Psychological needs (A_2), Economic needs (A_3), Group norms (A_4), Low-quality social exchange relationships (A_5), Work stress (A_6), Work experience (A_7), Safety accidents (A_8)
Constant	Time and effort saving (C_1), Pursuit of comfort (C_2), Self-esteem needs (C_3), Sensation seeking (C_4), Increase of income (C_5), Blind conformity (C_6), Expedient conformity (C_7), Discord with workmates (C_8), Destructive leadership (C_9), Weak sense of belonging (C_{10}), Schedule pressure (C_{11}), Leadership pressure (C_{12}), Accident rate (C_{13}), Fluke psychology (C_{14}), Paralysis psychology (C_{15}), Safety regulations (C_{16}), Safety supervision (C_{17}), Safety training (C_{18}), Safety management commitment (C_{19}), Workers' participation in safety (C_{20}).

$$\mathbf{A_7 = WITH\ LOOK\ UP\ (time)}$$

$$\mathbf{A_8 = S_1 \times C_{13}}$$

Where l_{11} and l_{12} are the weights of C_1 and C_2. WITH LOOK UP (time) indicates the relationship between work experience and time, and the specific data were collected through the questionnaire survey. Other auxiliary variable equations can be given with reference to the equations of A_1, A_7, and A_8.

For the case where one outcome factor corresponds to multiple cause factors, the G1 method was utilized to determine the weights of each factor, which effectively circumvents the shortcomings of hierarchical analysis process and is simple to operate without requiring consistency testing (Chu et al., 2018). Furthermore, the expert scoring method was chosen for the case where one cause factor corresponds to one outcome factor. Five corporate experts with extensive construction management experience and seven university researchers were invited to score and determine the weights of these factors. The basic information of experts is shown in **Table 6**, and the final weight of each factor are shown in **Table 7**.

In order to determine the initial value of state variables and constants, the data was obtained through distributing research questionnaires to more than 200 NGCWs whose workplaces were in 13 provinces and municipalities, including Jiangsu, Henan, Shandong, Jiangxi, etc. A total of 128 valid questionnaires were returned, and the results of data analysis showed that the reliability and validity met the requirements. In addition, the data collected was dimensionless processed for the purpose of comparability. **Table 8** shows the initial value of factors. Among them, the value of C_{13} was set as 0.090, which determined by Heinrich ratio (i.e., in a unit group of similar 330 accidents, 1 will result in major injury, 29 will result in minor

TABLE 6 | Basic information of experts (N = 12).

Variable	Categories	Number of Cases	Frequency (%)
Sex	Male	11	92%
	Female	1	8%
Age	Between 21 and 30	2	17%
	Between 31 and 40	3	25%
	Between 41 and 50	4	33%
	Between 51 and 60	3	25%
Degree	Bachelor	6	50%
	Master	2	17%
	Doctor	4	33%
Affiliation	Construction company	2	17%
	Consultant company	3	25%
	College and university	7	58%
Professional Title	Lecturer	2	17%
	Associate professor	3	25%
	Professor	2	17%
	Engineer	4	33%
	Senior engineer	1	8%
Work Experience	Between 6 and 10 years	2	17%
	Between 11 and 15 years	6	50%
	Between 16 and 20 years	0	0%
	More than 20 years	4	33%

TABLE 7 | The weight of factors.

Outcome factor	Cause factor	Weight	Outcome factor	Cause factor	Weight
R_1	S_2	$f_{11} = 0.375$	R_8	A_8	$f_{81} = 0.340$
	S_3	$f_{12} = 0.270$		S_7	$f_{82} = 0.355$
	S_4	$f_{13} = 0.355$		S_8	$f_{83} = 0.305$
R_2	A_8	$f_{21} = 0.180$	R_9	S_8	$f_{91} = 0.359$
	S_6	$f_{22} = 0.210$		C_{19}	$f_{92} = 0.305$
	S_7	$f_{23} = 0.152$		C_{20}	$f_{93} = 0.336$
	S_8	$f_{24} = 0.167$	R_{10}	A_8	$f_{101} = 0.253$
	A_7	$f_{25} = 0.143$		S_1	$f_{102} = 0.130$
	S_5	$f_{26} = 0.148$		C_{17}	$f_{103} = 0.217$
R_3	A_1	$f_{31} = 0.140$		C_{16}	$f_{104} = 0.207$
	A_2	$f_{32} = 0.121$		C_{18}	$f_{105} = 0.193$
	A_3	$f_{33} = 0.164$	A_1	C_1	$l_{11} = 0.533$
	A_6	$f_{34} = 0.204$		C_2	$l_{12} = 0.467$
	A_5	$f_{35} = 0.208$	A_2	C_4	$l_{21} = 0.459$
	A_4	$f_{36} = 0.164$		C_3	$l_{22} = 0.541$
R_4	A_7	$f_{41} = 0.833$	A_3	C_5	$l_{31} = 1.000$
R_5	C_{14}	$f_{51} = 0.527$	A_4	C_6	$l_{41} = 0.486$
	C_{15}	$f_{52} = 0.473$		C_7	$l_{42} = 0.514$
R_6	A_8	$f_{61} = 0.356$	A_5	C_8	$l_{51} = 0.282$
	S_7	$f_{62} = 0.343$		C_9	$l_{52} = 0.449$
	S_8	$f_{63} = 0.302$		C_{10}	$l_{53} = 0.270$
R_7	S_6	$f_{71} = 0.529$	A_6	C_{11}	$l_{61} = 0.480$
	A_7	$f_{72} = 0.471$		C_{12}	$l_{62} = 0.520$

injuries, and 300 are non-injury accidents) (Heinrich, 1931). The initial value of A_7 was set as 0.288 through replacing work experience with work time.

TABLE 8 | The initial value of factors.

Factor	Initial value	Factor	Initial value
S_1	0.210	C_8	0.253
S_2	0.347	C_9	0.324
S_3	0.620	C_{10}	0.290
S_4	0.292	C_{11}	0.435
S_5	0.750	C_{12}	0.390
S_6	0.623	C_{13}	0.090
S_7	0.711	C_{14}	0.290
S_8	0.745	C_{15}	0.293
C_1	0.342	C_{16}	0.734
C_2	0.318	C_{17}	0.749
C_3	0.265	C_{18}	0.751
C_4	0.213	C_{19}	0.706
C_5	0.388	C_{20}	0.715
C_6	0.380	A_7	0.288
C_7	0.343		

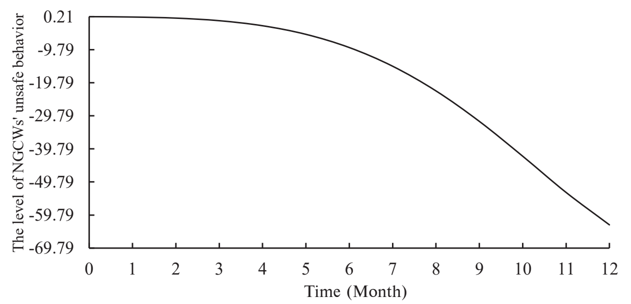

FIGURE 4 | Evolution trend of NGCWs' unsafe behavior.

Simulation and Analysis

Using Vensim PLE software for simulation, and the initial level of NGCWs' unsafe behavior was set as 0.21. Additionally, setting the parameters as follows: INITIAL TIME = 0, FINAL TIME = 12, TIME STEP = 1, SAVEPER = TIME STEP, UNITS FOR TIME = MONTH, and taking 1 year as the simulation period. Firstly, the initial state simulation of the model was conducted. Secondly, the input values of motivation for unsafe behavior, each situational factor and each individual factor were modified in turn, while keeping the input values of the remaining factors invariant to identify the key factors.

In the initial state, the simulation result is indicated in **Figure 4**. As can be observed from **Figure 4**, under the synergistic effect of multiple factors, the level of unsafe behavior shows a downward trend with a three-stage characteristic, and the rate of decrease is slow first and then fast with the continuous advancement of project construction work. To be specific, in the first stage (months 0–4), the level of unsafe behavior remains the same overall with a slight decrease. The high level of unsafe behavior indicates that the safety performance of the whole system is insufficient at the beginning of the simulation. In the second stage (months 4–8), the decline rate of the level of unsafe behavior gradually accelerates. In the third stage (months 8–12),

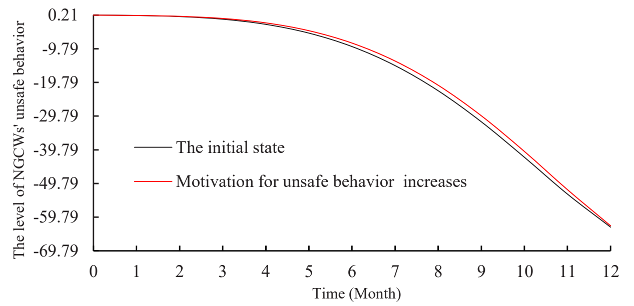

FIGURE 5 | Simulation of the effect of motivation for unsafe behavior on unsafe behavior.

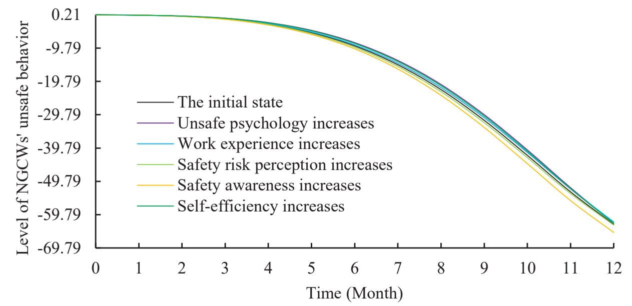

FIGURE 6 | Simulation of the effect of individual factors on unsafe behavior.

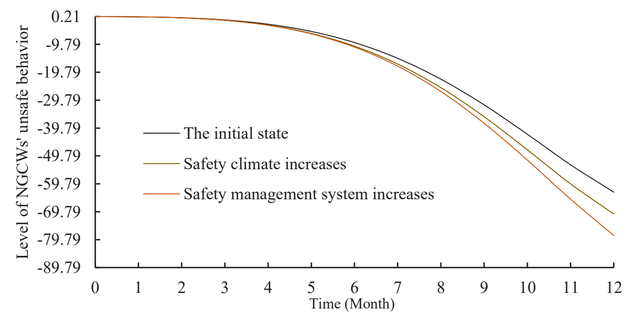

FIGURE 7 | Simulation of the effect of situational factors on unsafe behavior.

the level of unsafe behavior shows a more significant decreasing trend. It can be found that situational factors such as safety management system and safety climate have been improved over time, which has led to an improvement in NGCWs' personal traits such as safety awareness and risk perception. The result of initial simulation validate to an opinion that a large number of construction accidents occur during the early phase of a construction project (Shin et al., 2014). In addition, although NGCWs' unsafe behavior can be effectively curbed as time continues to pass, the apparent effect of the intervention is lagging, so the time for workers to become familiar with the intervention should be minimized.

To analyze the effect of motivation on the level of unsafe behavior, this study kept the input values of other factors unchanged and increased the inflow of motivation for unsafe behavior by 0.2. As shown in **Figure 5**, the overall trend of the level of NGCWs' unsafe behavior increases. The input values of each individual factor and each situational factor were increased by 0.2 as well to explore their effects on the level of NGCWs' unsafe behavior. The simulation results are shown in **Figures 6**, **7**. In terms of individual factors, the increase of self-efficacy and unsafe psychology will lead to the increase of unsafe behavior's level, but the effect is non-significant; the increase of safety risk perception and safety awareness will lead to the decrease of unsafe behavior's level, and the effect of safety awareness is more significant; the effect of work experience on unsafe behavior's level has a phased feature of decreasing in the first 2 months and increasing in the next 10 months, but the effect is relatively weak. In terms of situation factors, the increase of both safety management system and safety climate can effectively reduce unsafe behavior's level, and the effect of safety management system is more obvious. Moreover, the simulation trend after changing the input values of each variable is similar to the initial state, which indicates that the established system dynamics model is relatively stable (Yu et al., 2019).

DISCUSSION

Theoretical Contributions

First, this manuscript creatively expands the SOR model, introduces the result link and constructs the SORR behavior chain. Then, based on this theoretical framework, from the perspective of the driving force of behavior, i.e., behavior motivation, this manuscript explores the formation mechanism of NGCWs' unsafe behavior through qualitative research. The results show that the SOR theory can effectively explain and predict unsafe behavior at construction sites. The manuscript introduces the SOR theory into the field of behavioral safety and expands the application scope of this theory. Besides, the formation mechanism of unsafe behavior mainly aims to deeply explore the logical relationship between the concerned events and the causal factors (Huang et al., 2019). This explanation of the random combination of influencing factors breaks through the limitations of the single factor analysis. In addition, previous studies on the formation process of unsafe behavior have been conducted from the perspective of cognition (Fang et al., 2016), risk perception (Huang et al., 2019), etc., and rarely from the perspective of motivation. Therefore, this study provides a new insight into how construction workers' unsafe behavior occurs, which is a perfection and supplement to the existing literature.

Second, this study breaks through the traditional research on the static relationship between antecedent factors and unsafe behavior, analyzes the dynamic performance of construction workers' unsafe behavior from a systematic perspective, presents the feedback structure of various factors in the system, and responds to the call for a comprehensive understanding of the potential mechanism using systems thinking (e.g., Jiang et al., 2015). The dynamic evolution laws obtained by computer simulation clearly presents the trend of change of

NGCWs' unsafe behavior that impacted by complex construction environment and multiple factors. Namely, the level of NGCWs' unsafe behavior shows a downward trend with a three-stage characteristic and the rate of decrease is slow first and then fast during the construction period.

Third, previous research on the new generation of migrant workers has focused on city integration (Zheng, 2021), entrepreneurial willingness (Lin and Mai, 2018), entrepreneurial performance (Ma et al., 2018), etc., but has ignored the unsafe behavior of this group based on the context of China's construction industry. The formation mechanism and dynamic evolution laws about unsafe behavior found by this manuscript enrich the body of knowledge of unsafe behavior among young construction workers. In contrast to previous studies, this study highlights the important roles played by physiological needs, psychological needs, self-efficacy, work experience and low-quality social exchange in the formation of unsafe behavior for the young construction workers in the Chinese context, which can also be clearly reflected in the laws of dynamic evolution.

Managerial Implications

The findings also have important managerial implications for construction companies and government departments. According to the formation mechanism model, the NGCWs' internal needs and external incentives can stimulate corresponding motivations for unsafe behavior. Hence, it is of great importance to find ways to block the emergence of motivations for unsafe behavior. In addition, based on the simulation results in the previous section, safety management system and safety climate have the most significant effect on the level of unsafe behavior. Improving the safety management system as well as creating a positive safety climate is an essential grip to curb the occurrence of NGCWs' unsafe behavior.

Compared to older workers, younger workers usually have lower tolerance capacity. The study found that the NGCWs are likely to perform unsafe acts, such as not wearing PPE, because of the need to save time and effort and for comfort. Construction workers' discomfort when using PPE may be caused by differences in the design and workmanship of different brands of PPE (Wong et al., 2020). One of the key takeaways for construction companies is the need to maximize safety equipment's comfort and ease of operation while ensuring their security and reliability. This requires construction companies to increase investment in safety resources to ensure that safety facilities are adequate and reasonable. The results of the interviews suggest that self-esteem needs and sensation seeking may induce NGCWs' hazardous acts. Therefore, effective safety education is necessary to guide them to establish the view of safety first. Besides, the economic need is one of the triggers of NGCWs' unsafe behavior. A reasonable worker compensation system and wage increase mechanism should be set. On the basis of ensuring the basic income, workers ought to get additional compensation or job promotion opportunities according to the virtue of their work quality, professional skill level and skill qualification certificates, etc. Government departments should implement effective supervision of the payment of migrant workers' wages and impose severe penalties on construction companies for wage defaults. Considering the unsafe influence of schedule pressure and leadership pressure, reasonable work intensity and leadership attention to safety are conducive to reducing the motivation for unsafe behavior caused by work pressure. Therefore, work tasks should be reasonably assigned and rest time should be flexibly arranged. In terms of group norms, workers should be encouraged to communicate with each other about safety and be bolstered to think independently by setting a denounce system. The results also suggest that poor quality of social exchange relationships can lead to the motivation for unsafe behavior. Construction companies need to conduct more activities to enhance the relationships of workers, co-workers, and leaders, so as to improve workers' sense of organizational identity, belongingness and job satisfaction. Leaders also need to show concern for workers and have regular safety-related communication and exchange with them.

Furthermore, the forms of safety training can be updated to improve the effectiveness of safety training for NGCWs. Aside from the traditional centralized and indoctrination-based safety training, forms that are more likely to arouse the interest of NGCWs can be adapted, for example, VR technology can be applied to further improve the safety performance of NGCWs (Nykanen et al., 2020). Government departments also need to actively monitor the quantity and quality of safety training for construction companies and check the effectiveness of the training. In terms of safety supervision, managers at all levels should actively perform their safety supervision duties to eliminate the "formalism" of safety management. It is the responsibility of the construction company to provide sufficient human resources to maintain close safety supervision as well (Wong et al., 2020). Moreover, while construction companies continue to improve safety regulations, government departments have the responsibility to assess the safety regulations. In addition, construction companies need to pay attention to the role of safety climate in curbing NGCWs' unsafe behavior. Safety knowledge competitions and safety meetings can be held to improve the safety climate at construction sites. A positive safety climate also influences other factors, such as safety awareness (Wang et al., 2018). Finally, interventions need to be implemented for NGCWs as early as possible to quickly and effectively curb their unsafe acts.

Limitations and Future Work

The manuscript still has some shortcomings and deserves further improvement in future studies. First, grounded theory still has the risk of confirmation bias to some extent. In future studies, the researchers' interviewing and coding skills could be further enhanced to identify some information that might be missed. Second, comparative analysis between the new and old generations of construction workers is meaningful, and either qualitative or quantitative research methods can be used to conduct controlled analyses to identify specific differences in unsafe behavior between the two groups and to propose more targeted improvement measures. Third, the data collected from the questionnaire survey and expert scoring method are somewhat subjective in assigning values to some of the variables in the system dynamics model, and future research can adopt a more objective approach to improve the accuracy of the simulation results.

CONCLUSION

At present, the research on the formation mechanism of construction workers' unsafe behavior from the perspective of behavior motivation is still in the early stage. As a major component at construction sites and an important driver of China's current economic development, the NGCWs should receive more attention about their safety. In this regard, this manuscript portrays the formation mechanism of their unsafe behavior based on grounded theory. In this process, the SOR theory is expanded to provide a suitable research framework. In addition, based on systems thinking, system dynamics models of NGCWs' unsafe behavior are constructed to explore the dynamic evolution laws and the effect of influencing factors. The conclusions can be drawn as follows:

(i) The formation process of NGCWs' unsafe behavior involves three stages, including behavior motivation stimulation stage, behavior motivation externalization stage, and behavior result generation stage. Motivations for unsafe behavior can be stimulated by internal needs (i.e., economic, physiological, and psychological needs) and external incentives (i.e., work stress, group norms and low-quality social exchange relationships). Influencing factors in the decision-making process of externalizing motivation into behavior include individual factors (i.e., work experience, self-efficacy, safety risk perception, unsafe psychology, and safety awareness), situational factors (i.e., safety management system and safety climate) and behavior result.

(ii) Under the synergy of various factors, with the continuous progress of project construction, the level of NGCWs' unsafe behavior tends to decrease, and the decline rate is slow first and then fast. The increase of the motivation for unsafe behavior will aggravate the occurrence of unsafe behavior. Improving both individual factors and situational factors can reduce the level of NGCWs' unsafe behavior, and the role of situational factors is more obvious.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

GN contributed to conception and design of the study. LL, SW, XM, and QL collected the data. LL and SW contributed to the data analysis. LL, SW, and XM contributed to the original draft of the manuscript. GN, LL, YF, and QL contributed to the review and editing of the manuscript. All authors have read and agreed to the Published version of the manuscript.

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APPENDICES

Appendix A. Outline of the interview with the new generation of construction workers (NGCWs).

Q1. Have you ever experienced or heard of some safety accidents that impressed you during your work? Can you explain the incident in detail?
Q2. Do you think these safety accidents are caused by human factors or objective factors?
Q3. Can you explain what is unsafe behavior? What unsafe behavior do you have in your daily work?
Q4. Why do you perform these actions since you know they are unsafe? Please list at least three reasons.
Q5. Would you do this in any situation? When would you not perform these unsafe acts?
Q6. What unsafe behavior exists among the young workers around you? Why do they do this?
Q7. Have you ever considered the consequences of unsafe behavior? What do you think the impact of unsafe behavior will be on yourself, workmates and family?
Q8. Assuming that these unsafe behaviors resulted in injury or death to others or yourself, how would your intentions and attitudes toward similar behaviors be affected?

Appendix B. Outline of the interview with the grassroots manager.

Q1. What is the proportion of NGCWs at the construction site you are responsible for? What is the difference between them and the old generation of construction workers?
Q2. How do you think NGCWs performs at work? What are the characteristics of their work attitude and work behavior?
Q3. What unsafe behavior occurs among NGCWs at project sites and how frequently it occurs?
Q4. Why would they perform unsafe behavior? What are the possible motivations and reasons? You can give examples.
Q5. What is the impact of their unsafe behavior?
Q6. What measures does your project department have to deal with the NGCWs' unsafe behavior?
Q7. What else can be done to reduce NGCWs' unsafe behavior?

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Study on Influencing Factors of Micro and Small Enterprises' Work Safety Behavior in Chinese High-Risk Industries

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Due to the limited work safety resources and the poor awareness of work safety from business owners with absolute decision-making power, safety accidents frequently occur in Chinese micro and small enterprises (MSEs) in high-risk industries. This study identifies the influencing factors of work safety behavior from MSEs, government safety supervision departments, and work safety service agencies. Based on the theory of planned behavior (TPB), the mechanism model of work safety behavior is built from the aspects of behavior attitude, subjective norms, behavior control cognition, past behaviors, and risk awareness of the enterprise. Based on the interview with nearly 600 MSEs in the east of China over 6 months, the results show that the work safety awareness of the business owner determines the work safety lever of the enterprise, and the work safety behavior of MSEs is a passive restraint behavior. Our findings provide a new perspective on the formation of MSEs' work safety behavior in high-risk industries.

Keywords: work safety behavior, influencing factors, MSEs, high-risk industries, theory of planned behavior, complex social system

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INTRODUCTION

Micro and small enterprises (MSEs) are the lifeblood in China's economic and social development in recent years. It plays a pivotal role in China such as promoting economic growth, transformation, and upgrading; optimizing economic structure; expanding employment; increasing income; and improving people's livelihood (Tremblay and Badri, 2018). Compared with foreign enterprises and state-owned large and medium-sized enterprises, MSEs, as the most dynamic group in China's economy, are also the most vulnerable. High-risk MSEs have problems such as failure to implement work safety responsibilities, weak safety awareness, and confusion in safety management. In April 2018, during the transportation of explosives, a dangerous transport vehicle belonging to Gushi County Chemical Co., Ltd., Henan in Yuehe Town, Zhen'an County, Shanxi Province, exploded due to the transporter's unsafe operation, causing seven deaths and nineteen injuries. To minimize the operating costs, the plant infrastructure of the MSEs is primitive with hidden dangers. Production technology is backward, and the work environment is adverse. It can be seen that the MSEs have problems of "lack management" or "unable to manage" (Olsen and Hasle, 2015), so serious accidents occur frequently. According to statistics in China, in recent years, more than 70% of major accidents are concentrated in MSEs in high-risk industries, especially coal production, transportation, and construction engineering. The frequent occurrence of major accidents in high-risk industries has not been effectively curbed. The work safety situation is still grim, and there are still a large number of accidents.

Since MSEs in high-risk industries are small in scale, difficult in financing, difficult in employment, and high in operating costs, it is difficult for enterprises to realize work safety with limited profit space. Business owners have a fluke mentality for safety accidents, lack awareness of work safety, and lack pressure and initiative for work safety. At the same time, "Accidents Occurring-Inspection and Regulation-Closing" has become the routine for the work safety supervision department to deal with work safety accidents (Mei et al., 2017). The government focuses on the time and quantity of the work safety of MSEs. The insufficient supervision or partial supervision failure by the government supervision department causes it difficult to curb the accidents from the source; in addition, work safety service agencies are more concerned about how to satisfy the standards more easily. Due to the lack of supervision and constraint, these agencies even collude with enterprises to implement the standards. It is too formalistic for MSEs in high-risk industries, government work safety supervision departments, and work safety service agencies to implement work safety behaviors.

To explore the influence factors of the work safety behaviors, the enterprise business owners are taken as the research object to fully explore the mechanism of the work safety behavior of MSEs in high-risk industries. In this study, more than 600 MSEs in the east of China are selected. These enterprises are mainly involved in high-risk industries such as constructional engineering, transportation, hazardous material production and storage, non-coal mining, machinery manufacturing, fireworks production, and metallurgy. It is expected to demonstrate the internal influence mechanism of the enterprise behavior attitude, subjective norms, perceptual control behavior, enterprise past behavior, and risk preference on the work safety behavior of MSEs in Chinese high-risk industries.

LITERATURE REVIEW

Recently, a study on the work safety behavior of MSEs in high-risk industries focuses more on the supervision of enterprises, the safety evaluation of enterprise accidents in high-risk industries, and the work safety entrust. The work safety supervision of high-risk MSEs is complex, and the spontaneous evolution modes of supervision strategies are analyzed. It is necessary for high-risk enterprises to obtain work safety licenses to engage in production, and one of the conditions for obtaining a work safety license is to pass the safety evaluation (Zhang et al., 2017). For the convenience of subsequent research, the work safety behaviors are divided into forward and reverse aspects (Liu et al., 2015). As the basic organizational form and entities of economic activities, enterprises have "organizational behaviors" in safety activities (Daft, 2012), i.e., "the safety behavior of the enterprises." The behavior directly affects the safety of people and the things, and it directly affects the safety level of the enterprise. The work safety behavior of an enterprise mainly reflects the safety decisions by managers or management who have budget decision-making power, resource allocation power, and job placement priority (Liu et al., 2012). Combined with the decision made by the MSE owners with decision-making power, the work safety behaviors of MSEs are divided into two dimensions, namely, work safety behavior and work unsafe behavior. Based on the current situation, work safety behaviors can be realized by purchasing work safety services or implementing the safety standard independently. Thus, work safety behaviors are divided into service-oriented work safety behavior and independent work safety behavior.

The theory of planned behavior is a mature theoretical research model developed on the basis of the theory of reasoned action. Ajzen put forward the theory of reasoned action based on the theory of multi-attribute attitudes firstly (Ajzen, 1985), and it was continuously improved to form the theory of planned behavior (TPB). There are many empirical studies on predicting and explaining individual behavior through the theory of planned behavior, but there are few studies on explaining the behavior decisions of enterprises (organizations) by using the theory of planned behavior. The business owners (top management) of MSEs make decisions on the work safety behavior of the enterprise. Combined with the work safety characteristics of MSEs in high-risk industries, it is feasible to study the mechanism of work safety behavior of MSEs based on the theory of planned behavior. Based on the theory of planned behavior, the influence of three traditional variables on behavioral intention and behavior is considered when the work safety behavior of MSEs is studied. Among them, behavior attitude mainly reflects the cognition of business owners with decision-making power to the enterprise work safety, which involves the enterprise strategic planning, operation management, and specific work safety behaviors (Mullen et al., 2017). The subjective norms originate from external constraints on enterprises, and it involves two aspects, namely, constraints and norms. The perceptual behavior control mainly reflects the resource support that is beneficial to the work safety behavior of enterprises.

IDENTIFICATION OF INFLUENCING FACTORS

Analysis of Stakeholders on Work Safety Behavior of Micro and Small Enterprises

The work safety behavior of MSEs in high-risk industries is mainly influenced by the stakeholders such as MSEs, government safety supervision department, work safety service agencies, and external environment, as shown in **Figure 1**.

(1) Influencing factors of work safety behavior of MSEs:

Due to a variety of subjective and objective factors such as the research field, there are large differences in the analysis dimensions of work safety behavior. The enterprise work safety behavior includes management commitment, safety training, employee participation, safety communication and feedback, safety regulations, and safety improvement strategies

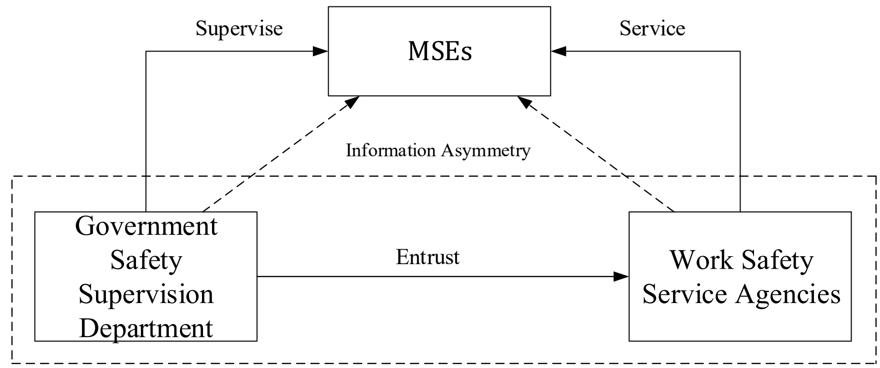

FIGURE 1 | Operating system structure of the work safety behaviors of micro and small enterprises (MSEs).

(Vinodkumar and Bhasi, 2010). From the perspective of safety atmosphere, it can be divided into management values, management practices, communication, and employees' involvement in safety and health in the workplace (Neal et al., 2000). Based on the factor analysis method, the work safety behavior can be divided into seven dimensions, including manager safety, work safety, colleague safety, safety management, safety training, safety regulations, special safety training, and work pressure (Liu et al., 2009). In China, there are many methods to divide the work safety behavior, including classification based on the nature of safety investment and classification based on the function of safety investment (Chen et al., 2004; Lu and Mei, 2008).

In high-risk industries, Cooper studied the impact of managers' participation in enterprise safety on employee work safety behavior, and the results showed that the safety participation of enterprise managers greatly influences the unsafe behavior of employees of the enterprise. The manager with a higher position can influence the behavior of the employees more (Cooper, 2006). The senior managers influence the behavior of the lower managers and then the behavior of the entire enterprise. Hence, the business owners (top managers) of MSEs play a leading role in the work safety behavior decision of MSEs.

In this study, the influencing factors of work safety behaviors of MSEs are divided into the following four aspects: the cognitive factors of business owners, i.e., the impact of managers on work safety awareness; the organizational factors, i.e., the impact of industry characteristics and organizational structure of MSEs; the economic factors, i.e., the impact of work safety behaviors of MSEs on cost accounting and benefit analysis; the risk factors, i.e., risk identification of MSEs and its impact on consciousness behavior.

The cognitive factors refer to the behavior attitudes of MSEs' owners toward work safety behaviors. It involves the integration of enterprise strategic positioning, emphasis, and positive measures. The managers of MSEs control the decision-making power and management power of the enterprise. The implementation and decision-making of the enterprise work safety behavior depend on the safety awareness of the business owner, and it guides the enterprise work safety behavior. Business owners with higher safety awareness implement work safety behaviors actively and positively, while business owners with lower safety awareness often passively or even do not implement work safety behaviors. It can be seen that the attention of micro and small enterprise owners give to work safety behavior and their awareness of taking the initiative to implement work safety behavior directly affect the work safety behavior of MSEs.

The organizational factors refer to factors such as whether an enterprise has established a special safety management organization, the operation mechanism, and the authority of these organizations. According to the "Law on Work Safety" in China, special safety management agencies or full-time safety management personnel are required in enterprises in high-risk industries, including mines, construction organization, and units that produce, operate, and store hazardous materials. Through the preliminary investigation of MSEs in high-risk industries in Jiangsu Province, it is found that the work safety management department is set in 32% of MSEs; in 65% of MSEs, work safety agency functions are supervised by other departments within the enterprise; and there is no work safety agency in a few individual operation enterprises. In addition, there is no full-time or part-time safety management personnel in most MSEs, and some special operations personnel do not have certificates. The work safety of many MSEs without safety management institutions is basically neglected. Therefore, the imperfect work safety management organization of enterprises and the lacking full-time and part-time safety management personnel are regarded as organizational factors affecting the work safety behavior of MSEs.

The economic factors are one of the important influencing factors restricting the work safety behavior of MSEs. This part is studied from the perspective of the safe investment behavior of business owners. It is believed by enterprises that safety investment only increases the cost of the enterprise and there are no economic profits. From the reality of MSEs in high-risk industries, all expenses related to enterprise safety are not calculated and managed separately but included in various departments or corresponding expenses as production costs and management expenses (Lu and Mei, 2010). The lack of a safety cost accounting system limits the ideas of cost control for MSEs. Without the objective understanding of safety

TABLE 1 | Classification of influencing factors of work safety behavior of micro and small enterprises (MSEs).

Category	Influencing factors	Specific description
Internal factors of enterprises	Cognition factor of business owners	The attention of business owners to work safety, business owners' willingness to invest in safety, or the role of work safety in strategic planning
	Organization factors	The industry characteristics (whether it is a high-risk industry), the setting and perfection of work safety management organization, and the configuration of full-time (or part-time) safety management personnel, etc.
	Economic factors	The accounting of safety cost in cost accounting (classification), the proportion of safety cost in the total cost, whether the safety cost brings direct benefits (or indirect benefits) to the enterprise, the proportion of the safety cost, etc.
	Risk factors	The ability to identify the existing hazards of the enterprise, the ability to regulation and restraint of major hazards, and the business owners' awareness of risk-taking
Enterprise stakeholders	Government regulation	Setting of the safety department and safety management personnel in local government are efforts in supervising, whether there are regular safety inspections. The implementation of the administrative license for work safety, whether effective potential danger rectification and tracking procedures are established.
	Safety demands from employees	Whether the enterprise conducts safety education and training for employees, whether employees can identify hazards at work, whether the enterprise provides all employees with necessary protective equipment and conduct regular inspection and maintenance, and whether the enterprise purchase injury insurance for employees
	Safety services and technical support of service agencies	Whether the enterprise can easily obtain the safety services of the safety intermediary organizations (such as training methods, standardization of technical services, etc.), whether the enterprise can implement the rectification opinions, whether the enterprise has formed a long-term cooperation with the organization, etc.
	Public opinion restraint	The safety demands of the public, whether the pressure of public opinion has a positive effect on the work safety behavior of MSEs, etc.
	Work safety behaviors of neighboring enterprises	The work safety strategy planning, and demonstration role of work safety behaviors of neighboring enterprises, etc.
	Safety standards of upstream and downstream enterprises in the supply chain	Whether suppliers, distributors, and consumers have signed information sharing contracts to control the binding force of enterprise work safety and safety protection, and there is a unified information system platform to achieve enterprise credit evaluation, etc.

TABLE 2 | The correspondence relationship between the exogenous variables and the influencing factors of MSEs' work safety behaviors in high-risk industries.

Influencing factors in the theory of planned behavior	Influencing factors of MSEs' work safety behavior
Behavior attitude	Business owners' awareness of work safety, strategic positioning of work safety issues in the enterprise, and the importance of work safety in the operation and management of the enterprise
Subjective norms	Government supervision, employee safety demands, implementation of rectification opinions in service agencies, public opinion constraints, industry norms constraints, the definition of safety standards of upstream and downstream companies in the supply chain
Perceptual behavior control	Constraints of the existing work safety resources of the enterprise (the establishment of enterprise work safety management department, the configuration of work safety management personnel), support of work safety policy in government, work safety technical support from service agencies
Behavioral habits	The past work safety behaviors of enterprises, the work safety behavior norms of neighboring enterprises
Risk awareness	The ability to identify the existing hazards of the enterprise, the ability to regulate and restrain the major hazards, and the business owners' awareness of risk-taking attempts

input-output-benefit, MSEs' judgment on safety benefits and their future safety investment are affected. In the enterprise operation, the enterprise's safety awareness or the severity of accidents is evaluated from whether the enterprise actively pays its employees' injury insurance. Lax enforcement causes lag, potential, the externality of safety benefits perceived by the enterprises, leading to the gap between the cost and benefit and the actual value of safety investment behaviors, which causes the improper safety investment of the enterprises.

The risk factors are the identification and attitude of micro and small business owners to risk and its impact on the risk-taking behavior of employees. In the production of enterprises, combined with the industry characteristics of enterprises, the new "Law on Work Safety" points out that the warning signs of major safety sources should be highly visible, personnel for special operations are required, and operation should be provided regularly and continuously. Micro and small business owners believe that risks may not cause harm to employees, they ignore the danger of safety accidents, and they put fluke psychology about the risks in the production. Business owners do not value risks, resulting in unsafe production behaviors of employees.

(2) Regulatory constraints of the government safety supervision department:

Based on the economic development, the work safety system in China has been constantly adjusted, and a new supervision and management system with "unified leadership by the government, department supervision in accordance with the law, enterprise taking full responsibility, public participation in supervision, and broad support from the whole society" has been formed (Li et al., 2006). However, due to the particularity of MSEs, they are at a disadvantage in the process of being supervised by the government in work safety. Most of the MSEs are located in townships, but there are no safety supervision institutions and personnel set in most of the townships. Even if there are safety supervision institutions and personnel, they have no law enforcement power, leaving gaps in safety supervision. The existing government management modes are unsuitable for the development. On the one hand, many government departments still follow the management modes under the planned economic system. They intervene directly in markets, instead of is making guidance, and inspect and charge for the market, instead of providing supervision services, without effective means of safety supervision; on the other hand, insufficient safety supervision. Many MSEs are in a state of safety supervision gap or supervision failure. From the perspective of safety supervision, there are problems in the work safety regulation of MSEs in China, such as poor work safety-related information and low effectiveness of work safety regulation. The work safety standards and the imperfect socialized service system for work safety behavior of MSEs have led to excessive regulation pressure of the government (Mei and Liu, 2010).

(3) Supporting from work safety service agencies:

Work safety service agencies are generated in the market economic system. Entrusted by government departments, it engages in specialized technical service activities such as work safety evaluation, certification, monitoring, inspection, and consulting services in accordance with *Work Safety Law*. With the gradual improvement and development of the market economic system, the work safety service organization can effectively solve the defects of MSEs' work safety such as insufficient human resources, incompatible safety facilities, and extensive work safety management. The evaluation, certification, qualification of occupational safety and health of employees, and safety training are finished by the work safety service organizations, so they are required to further improve their service levels and quality (Zhong et al., 2014). The government provides preferential policies for MSEs through certification, establishing or funding work safety service organizations, and encourages service agencies to provide MSEs with safety technical support, safety training, consulting, testing, and system demonstration. In addition, the government will also supervise the training effects and safety evaluation reliability of work safety service organizations, conduct tracking to ensure the service level of service organizations, and ban the unqualified service organizations.

(4) Other subjects of the external environment:

Research on the work safety behavior of MSEs does not only involve enterprises, government safety supervision departments, or work safety service agencies. Other influencing factors should be considered, such as the employee demands, the demonstration role of the work safety behavior of neighboring enterprises, the public opinion pressure, and the work safety constraints and regulations of upstream and downstream enterprises in the supply chain.

Influencing Factors of Work Safety Behavior of Micro and Small Enterprises

Influencing factors of the work safety behavior of MSEs in high-risk industries are analyzed from internal and external dimensions of enterprise to form a classification system, as shown in **Table 1**.

Based on the classic theory of planned behavior theory, considering the impact of past behaviors on the current work safety behavior of enterprises and the risk characteristics of high-risk industries, two exogenous variables, behavior habits, and risk awareness are introduced. Combined with these two factors, traditional behavior attitudes, subjective norms, perceptual behavior control, and behavioral habits affect the work safety behavior through the work safety behavioral intention.

Behavior attitude mainly reflects the cognitive factors of enterprise owners with decision-making power on work safety behavior of MSEs, involving enterprise strategic planning, operation management, and specific work safety behavior. Subjective norms are derived from external constraints on MSEs, which generally involve hard norms and soft constraints. Perceptual behavior control mainly shows the favorable resource for MSEs' work safety behavior, including internal work safety resources, capital and policy support provided by the government safety supervision department, and technical support provided by work safety service agencies. Behavior habits mainly consider the impact of the past behavior of enterprises and the behavior of neighbor enterprises on the work safety behavior of MSEs. Risk awareness reflects the risk characteristics of high-risk industries, including the identification of existing hazard sources, the standardized operation awareness of major hazard sources, and employees' conformity psychology. The connotation of these exogenous variables and the influencing factors based on stakeholders are studied, and the corresponding relationship is formed, as shown in **Table 2**.

HYPOTHESES

(1) Relationship hypothesis between behavior attitude (A) and behavioral intention (I) of MSEs in high-risk industries:

Ajzen tested the theory of planned behavior by behaviors such as losing weight, the attendance rate of college courses, and getting an "A" in college examinations. The research showed that the prediction of behavioral intention based on three independent variables: attitude, subjective norms and perceived behavior control is successful (Ajzen, 1991). The drivers' driving violation behavior was studied, and it was found that the motor vehicle driver's attitude toward driving violation behavior can be predicted through the mediating effect of behavioral intention (Ding, 2006). Pedestrians' motivations for violating traffic rules were studied, and self-assessment measurements were conducted on 146 pedestrians. The results showed that behavior attitude is related to behavioral intention, and behavior attitude,

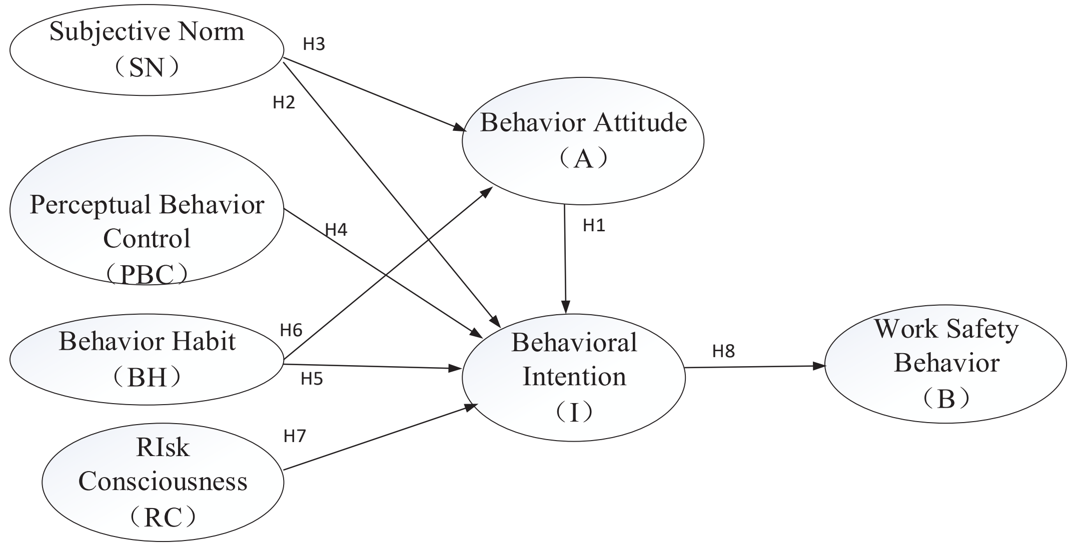

FIGURE 2 | A conceptual model for the influence mechanism of MSEs' work safety behavior in high-risk industries.

subjective norms, and perceptual behavior control are also related to each other (Diaz, 2002). Based on the theory of planned behavior, Lu studied the uncivilized behavior of tourists and found that the attitude of tourists in an unusual environment is the most influential factor of the uncivilized behavioral intention (Lu et al., 2019).

It can be seen that the influence of the behavior attitude, subjective norms, and perceptual behavior control on behavioral intention has been confirmed to varying degrees. Scholars at home and abroad have widely confirmed that behavior attitudes positively affect behavioral intentions (Hammami et al., 2013). Some scholars do not support the relationship between the two clearly, but they do not deny the direct connection between behavior attitude and behavioral intention.

As a durable and stable estimable psychological composition, behavior attitude can influence and predict the occurrence of behavior to a certain extent. Is the behavior taken by micro and small business owners determined by the attitude in high-risk industries? Therefore, the following hypothesis is proposed:

H1: Behavior attitude (A) positively affects the behavioral intention (I).

(2) Relationship hypothesis among the subjective norms (SN), behavior attitudes (A), and behavioral intention (I) of MSEs in high-risk industries:

There is a very significant correlation between subjective norms and behavioral intentions (Ajzen et al., 2011). Initially, subjective norms were parallel to behavior attitudes in the theory of reasoned action, and they influenced behavioral intentions as independent variables. Combined with the actual situation, it can be determined that subjective norms have a positive or negative influence on behavioral intentions (Huang et al., 2013). Subjective norms mainly reflect hard norms from government supervision and soft norms from employee safety demands, industry associations, public opinion, and upstream and downstream enterprises in the supply chain. The following hypothesis is proposed:

H2: subjective norms (SN) have a positive effect on behavioral intentions (I).

First, in the theory of reasoned action, subjective norms and behavior attitudes were in a parallel state, and they affected behavior intention as exogenous variables (Smith et al., 2007). The relationship is verified between subjective norms and behavior attitude by using empirical data. Moreover, subjective norms influence behavioral intentions. Lan found in empirical research that subjective norm does not affect behavioral intentions directly, but it influences behavioral intentions by acting on behavior attitudes (Lan and Zhu, 2009). It is necessary to analyze whether subjective norms affect behavioral intention indirectly through behavior attitudes of MSEs in high-risk industries. Thus, the following hypothesis is proposed:

H3: behavior attitude (A) plays a mediating role in the influence of subjective norms (SN) on behavioral intentions (I).

(3) Relationship hypothesis between perceptual behavior control (PBC) and the behavioral intention (I) of MSEs in high-risk industries:

The factors that cannot be explained by behavior attitudes and subjective norms are included in perceptual behavior control variables by many scholars. Based on TPB theory, Zhu constructed a configuration analysis model of internal employee entrepreneurial behavior (Zhu and Guo, 2020). The empirical results showed that the joint action of perceptual behavior control, behavior attitude, and subjective norms has multiple causalities and equivalence characteristics on internal employee entrepreneurial behavioral intention. The direct relationship between perceptual behavior control and behavior intention has been confirmed by empirical research of scholars. In this paper, the perceptual behavior control is integrated into the formation of favorable resource support for the work safety behavior of MSEs in high-risk industries, including the internal enterprise resources, the technical support and supervision management of the service organization, the policy support provided by the government, etc. It is necessary to analyze whether these resources have a positive effect on the formation of work safety behavior of MSEs in high-risk industries. The following hypothesis is proposed:

H4: Perceptual behavior control (PBC) positively affects the behavioral intention (I) of work safety.

(4) Relationship hypothesis among behavior attitude (A), behavior habit (BH), and behavioral intention (I) of MSEs in high-risk industries:

Many scholars believe that people always act in a certain way. Therefore, as long as this behavior has appeared, it is highly likely that the behavior will be repeated. "More than 90% of things people do every day are almost completely compliant with customary procedures," which is behavior habits. Past behavior improves the ability to predict behavior as a part of behavior control cognition in the theory of planned behavior (Norman and Cooper, 2011). Behavioral habits cannot be effectively included in the perceptual behavior control but enter into the model as an independent component. Behavioral habits influence behavioral intentions (Bagozzi and Yi, 1988). When the behavior is not perceived by the subject or when the behavior is in an unstable state, the behavior subject must consciously decide whether or not to perform the action. In this way, behavior is likely to affect behavioral intentions.

In addition, many other studies have confirmed that past behavior directly affects behavioral intention or behavior, not through attitude. For example, when the work safety behaviors are studied, the past behaviors or the influence of past experience are considered (Zwetsloot et al., 2011). If people tend to be accustomed to illegal actions, there may be a significant correlation between the past and future behaviors. It is believed that the previous violation did not cause an accident, so the behavior will not cause an accident. Therefore, the following hypotheses are proposed:

H5: Behavior habit (BH) significantly influences behavioral intention (I).

H6: Behavior attitude (A) plays a mediating role in the influence of behavior habit (BH) on behavioral intention (I).

(5) Relationship hypothesis between work safety risk awareness (RC) and behavior intention (I) of MSEs in high-risk industries:

The risk-related field was first proposed in the prospect theory. The theory proposed that people's decisions about gains and losses are asymmetric. Most people avoid risk when facing gains, but they prefer risk when facing loss. Based on the theory, a lot of studies on risk propensity were conducted. By analyzing the relationship between personality characteristics and risky behaviors, Niskanen found that there is a close positive correlation between people with high-risk preferences and risky behaviors (Niskanen et al., 2012). For users with high-risk tendencies, even the best safety signs are unlikely to be followed.

Larsson (2008) found that people with high-risk preferences are unwilling to follow safe behaviors. People with high-risk preferences do not adopt safe behaviors but an easier way during operation (Martínez-Córcoles et al., 2012). Combined with the hazard identification characteristics of MSEs in high-risk industries, individual awareness of the hazards is introduced, and the authors attempted to introduce the work safety risk awareness variable into the TPB. The following hypothesis is proposed:

H7: Risk consciousness (RP) significantly influences behavioral intention (I).

(6) Relationship hypothesis between work safety behavioral intention (I) and behavior (B) of MSEs in high-risk industries:

Ajzen believed that after the individual recognizes the behavior, with sufficient resources and opportunity, people will have behavior expectations and put them into action (Cordano and Frieze, 2000). Therefore, in a specific situation, the work safety behavioral intention produces a behavioral affecting the result after a certain behavioral expectation, which is an intermediary variable that causes work safety behavior. Hence, based on the definition of enterprise work safety planning and expected work safety resource input, the authors analyzed the significant influence of behavioral intention on work safety behavior of MSEs in high-risk industries and proposed the following hypothesis:

H8: Behavioral intention (I) influences work safety behavior (B) significantly.

CONSTRUCTION OF DECISION-MAKING THEORETICAL MODELS

Based on the above theoretical hypotheses, combined with the theory of planned behavior and the research conclusions by scholars, the influence of behavior attitudes, subjective norms, and behavior control cognition on behavioral intentions are studied. Meanwhile, risk preference and behavior habits are introduced to the model, and it is expected to understand whether two variables can significantly affect the work safety behavior and intention of MSEs. The behavioral intention reflects an individual's willingness to engage in a certain behavior, which is the most important predictor of behavior and directly determines work safety behavior. Therefore, the conceptual model of work safety behavior of MSEs in high-risk industries is constructed, as shown in **Figure 2**.

TABLE 3 | Industry distribution of the enterprises.

Industry	Number	Proportion (%)
Machinery manufacturing	162	36.4
Constructional engineering	72	16.19
Non-coal mining	19	4.27
Hazardous material production and storage	42	9.44
Transportation	17	3.82
Fireworks production	16	3.6
Metallurgy	117	26.28

TABLE 4 | Reliability test of the scale involved in the model.

Dimension	Item	Computed Cronbach's α
Behavior attitude (A)	7	0.849
Subjective norm (SN)	11	0.881
Perceptual behavior control (PBC)	8	0.821
Behavior habit (BH)	10	0.879
Risk consciousness (RC)	6	0.725
Behavioral intention (I)	5	0.858
Work safety behavior (B)	15	0.933

RESEARCH DESIGN

Based on authoritative theoretical viewpoints and scales used in the existing empirical research, combined with the actual situation of work safety behavior of MSEs in high-risk industries in China, an initial scale on work safety behavior of MSEs in high-risk industries is formed through expert interviews and consultations. An initial questionnaire test was conducted on 80 MSEs in high-risk industries in Jingkou District and Runzhou District of Zhenjiang City, Jiangsu Province. The high-risk industries include machinery manufacturing, chemical industry, metallurgy, transportation, and construction engineering. Finally, a formal questionnaire is obtained, as shown in **Supplementary Appendix**.

From December 2019 to June 2020, a questionnaire survey was conducted for MSEs in high-risk industries in the east of China, involving seven high-risk industries, including machinery manufacturing, constructional engineering, production and storage of hazardous material, transportation, non-coal mining, fireworks production, and metallurgy. A total of 600 questionnaires were issued, and 512 questionnaires were recovered. Among them, 445 valid questionnaires were received with a recovery rate of 74.17%.

Most of the MSEs surveyed are private enterprises, and small parts are companies with limited liability or self-employed. The business owners in high-risk industries are surveyed. In total, 36.4% of business owners have a college or bachelor's degree, and 53.2% of business owners have a high school degree. The enterprise information in high-risk industries surveyed is shown in **Table 3**.

TABLE 5 | EFA results of the perceived behavioral control.

Perceived behavioral control	Item	Factor loading			Eigen value (Explained variance)
		Common factor 1	Common factor 2	Common factor 3	
Internal source of the enterprise	PBC1	0.886			2.953 (32.672%)
	PBC2	0.898			
	PBC3	0.899			
	PBC4	0.888			
Support of service organizations	PBC5		0.786		1.978 (21.678%)
	PBC6		0.812		
	PBC7		0.811		
Government support	PBC8			0.764	1.532 (18.352%)
	PBC9			0.801	
Total explained variance	72.702%				

TABLE 6 | Convergence validity test results of the perceived behavioral control in CFA.

Perceived behavioral control	Item	Normalized factor loading	AVE	CR
Internal source of the enterprise	PBC1	0.886	0.797	0.9401
	PBC2	0.898		
	PBC3	0.899		
	PBC4	0.888		
Support of service organizations	PBC5	0.786	0.645	0.8449
	PBC6	0.812		
	PBC7	0.811		
Government support	PBC8	0.764	0.6126	0.7597
	PBC9	0.801		

Data Analysis

Reliability Test of the Scale

The Cronbach's α coefficient for reliability testing is a new method that is widely used. The higher the coefficient, the better the internal consistency. It is generally considered that the internal consistency is acceptable when the coefficient is greater than 0.7. **Table 4** shows the reliability of the scale in SPSS 22. The results show that the Cronbach's α coefficient of the seven variables are all greater than 0.7, showing a good internal consistency reliability.

Validity Analysis of the Scale

Validity analysis is generally divided into content validity, criterion validity, and construct validity. Among them, the construct validity is finished through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EFA is used to explore the underlying structure of the observed variables. CFA is used to test the existence of latent variables and factor structure.

Some scholars believe that if the scale designed is a mature scale, it can be tested by CFA. For scales constructed based on specific theories and actual situations, CFA and EFA are both needed to verify the construct validity of the questionnaire. For EFA, principal component analysis and the maximum variance method are used to extract eigenvalues and primary common factors (Wu, 2010). The items whose factor loading is less than 0.45 are eliminated. If it exceeds 0.7, the effect is the best. For CFA, the goodness-of-fit test and convergence effect test are conducted.

There are seven variables in the study of the work safety behavior of MSEs, including five exogenous variables, one intermediate variable, and one endogenous variable. The total number of questions for all variables is up to 63. It is difficult to carry out the validity test as a whole. This study tests the validity for each variable separately. Too many tests are finished in AMOS 24, and the test process is roughly similar. Here, the construct validity test of perceptual behavior control (PBC) is finished, and the test results are listed in **Table 5**.

There are 9 questions on perceptual behavior control, as shown in **Table 6**. This variable can explain 72.702% of the variance. The factor analysis results further show that common factor 1 can explain items PBC1-PBC4 better, common factor 2 can explain items PBC5-PBC7 better, and common factor 3 can explain items PBC8-PBC9 better, showing good convergence of the variable. Therefore, on the basis of perceptual behavioral control, three common factors are extracted, that is, three new variables are formed, which are named as internal resources of the enterprise (PBCCF1), support of service organization (PBCCF2), and government support (PBCCF3). These three common factors test the problems of the internal resources of the enterprise, the support of safety service organizations, and the policy support provided by the government.

Then, AMOS 24, AVE, and CR calculation tools are used to conduct the convergence validity of the scale. The results are shown in **Table 6**.

Among them, the AVE values are all greater than 0.5, and the CR values are all greater than 0.7, showing good convergence. The convergent validity is tested by perceptual behavioral control.

The results of the construct validity test show that behavior attitude (A), subjective norm (SN), risk consciousness (RC), and behavioral intention (I) identify a common factor; three common factors are identified by perceptual behavioral control (PBC), and they are internal resources of enterprise (PBCCF1), support of service organization (PBCCF2), and government support (PBCCF3); two common factors are identified by the behavioral habits, and they are the past behavior of the enterprise (BHCF1) and the code of conduct of neighboring enterprises (BHCF2); and three common factors are identified by work safety behaviors, and they are safety management (BCF1), safety training (BCF2), and safety prevention (BCF3). All of them pass tests and show good construct validity.

Model Fitting Test and Hypothesis Test

(1) Model fitting test:

The maximum likelihood method is used to estimate the model in AMOS 24. At the first fitting stage of the structural equation, as shown in **Table 7**, compared with the listed parameters of the fitting indicators, the ratio of chi-square degrees of freedom is 3.09 and the RMSEA is 0.0820, which do not meet the standard. Other parameter values meet the standard. The model needs to be further optimized and adjusted (Browne and Cudeck, 1992; Rong, 2009).

A model modification tool (Modification Indices) is provided by AMOS 24, and it can be used to adjust the goodness of fit. Because the influence of the "behavior habit" on "behavioral intention" (β = 0.133, T-value = 0.743) is not significant. After the hypothesis H5 is excluded, the parameter values of the fitting indices increase slightly, and the modified index is shown in **Table 8**.

The degree of freedom ratio of χ^2/df value is less than 3, the RMSEA is less than 0.08, and the values of IFI, CFI, GFI, and AGFI are ideal. The model fits well.

(2) The mediating effect test of behavior attitudes:

Bootstrap is the optimal method for mediating effect test, which is widely used in various fields. In this method, the research sample is taken as the sampling population, and new sample data are generated by repeatedly sampling the overall sample. The average value of the sampled parameter is the final estimation result to obtain a result that is highly accurate and reliable (Wen and Ye, 2014). Hypothesis 5 (H5) is excluded, and subjective norms affecting behavioral intentions indirectly through behavior attitudes are presented, so the mediating effect of safety attitudes is studied. The Bootstrap is used, the confidence interval is set to 95%, and the sample is run for 2000 times (Wen et al., 2010). The mediation effect is obtained in SPSS 22, as shown in **Table 9**.

First, the indirect effect value in the 95% confidence interval of the mediating effect is observed; it ranges from 0.1534 to 0.3321, and 0 is not included. The effect size is 0.2415, indicating that the mediating effect is significant. After the significance of mediating effect is tested, the direct influence test of the independent variable on the dependent variable is significant. Checked the direct effect value in the 95% confidence interval of the mediating effect, the value is in the interval (0.6901–0.8153), and 0 is not included. The effect size is 0.51. Therefore, the direct effect of the independent variable on the dependent variable is also significant. The mediating test of safety attitudes indicates that safety attitude plays a partial mediating effect, implying that subjective norms partially affect behavioral intentions directly and affect behavioral intentions through behavior attitudes indirectly.

(3) Hypothesis test:

Combined with the results of the optimized fitting and mediating effect test, the influence mechanism model of the work safety behavior of MSEs based on the theory of planned behavior is finally established (**Figure 2**). This model not only shows the direct influence of behavior attitudes, subjective norms, perceptual behavioral control, and risk tendency on behavioral intentions, but it also shows the indirect influence of subjective norms and past behaviors on behavioral intentions. It can be found that subjective norms have the greatest influence on behavioral intention through the mediating effect

TABLE 7 | Tests of goodness fit for the structural equations.

Index value	Computed X^2	X^2/df	GFI	RMSEA	AGFI	IFI	TLI	CFI
Amos test	1872.3	3.09	0.811	0.0820	0.918	0.901	0.912	0.907
Reference value	–	<3	>0.8	<0.08	>0.9	>0.90	>0.90	>0.90

TABLE 8 | Evaluation of modified model fitting.

Index value	Computed X^2	X^2/df	GFI	RMSEA	AGFI	IFI	TLI	CFI
Amos test	1275.96	2.058	0.898	0.071	0.821	0.921	0.968	0.956
Reference value	–	<3	>0.8	<0.08	>0.8	>0.90	>0.90	>0.90

TABLE 9 | Results of the mediating effect based on Bootstrap.

Path	Effect	Effect size	Squared error	95% confidence interval	
				Lower limit	Upper limit
Subjective norms→Safety	Indirect effect	0.2415	0.0453	0.1534	0.3321
Attitude→Safety intention	Direct effect	0.51	0.0325	0.6901	0.8153

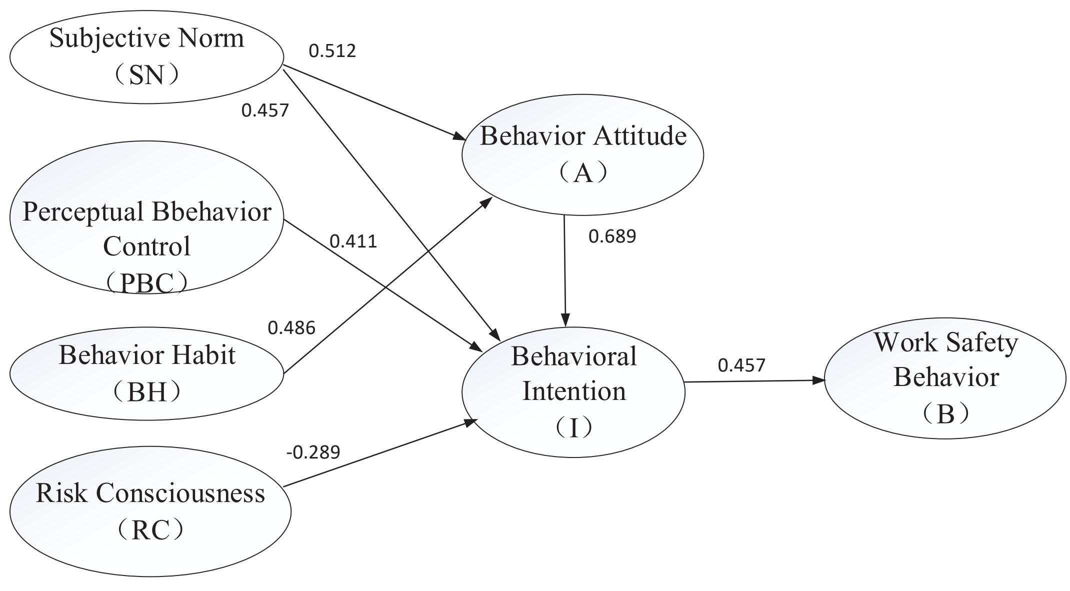

FIGURE 3 | Influence mechanism model of the work safety behaviors of MSEs based on the theory of planned behavior in high-risk industries.

of behavior attitude, and the influence coefficient is 0.81 (0.81 = SN→path coefficient of I + SN→path coefficient of A × A→path coefficient of I). For the influence of behavior attitude on behavior awareness, the influence coefficient is 0.689. Based on the theory of planned behavior, the influence mechanism model of the work safety behavior of MSEs in high-risk industries is constructed, as shown in **Figure 3**.

RESULTS

The following conclusions can be obtained through the above path analysis and mediation effect test:

(1) Work safety behavior attitude (A) positively affecting the behavioral intention (I) put forward by hypothesis 1 is verified, and its degree of influence is the highest. From the perspective of the path coefficient, the work safety behavior attitude most influences the behavioral intention (path coefficient is 0.689), which is higher than the direct influence of subjective norms or perceptual behavior control on the behavioral intention. It is proved theoretically that the behavior attitude of business owners is the main reason that directly affects the work safety behavioral intention of MSEs in high-risk industries (Mei et al., 2018). Changing the work safety behavior attitude of business owners is an important way to reduce work unsafe behaviors of MSEs.

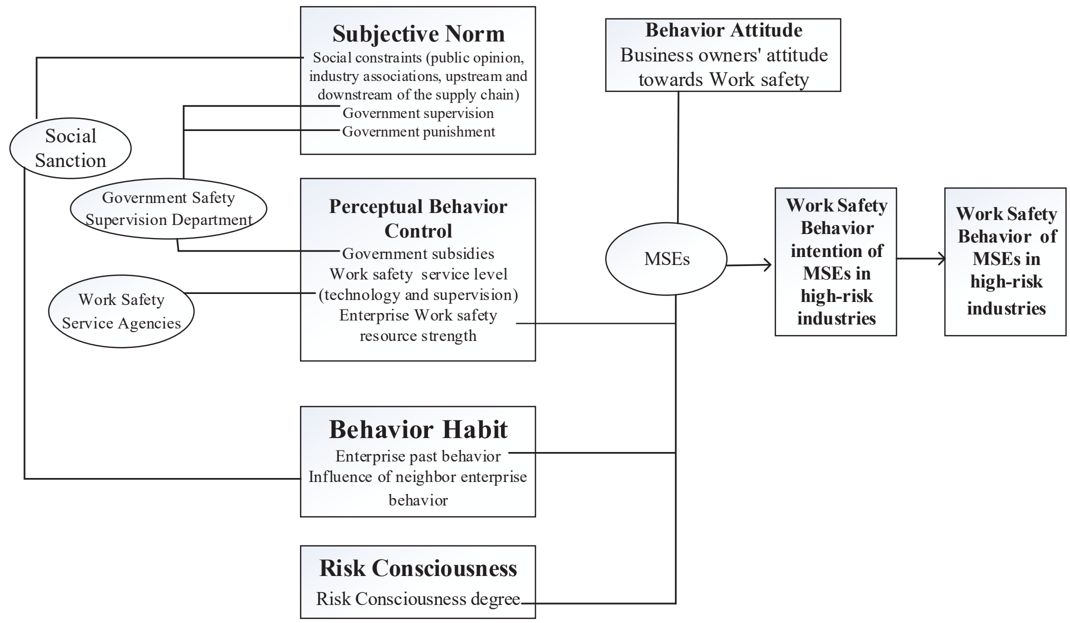

FIGURE 4 | Influence mechanism of work safety behaviors of MSEs in high-risk industries.

(2) Work safety subjective norms (SN) positively affect the behavioral intention (I), and the work safety behavior attitude (A) plays a mediating role in the influence of work safety subjective norms (SN) on behavioral intention (I). From the perspective of the path coefficient, the subjective norm is significantly correlated with behavioral intention (path coefficient is 0.457). Combined with the mediating effect testing, the behavior attitude plays a mediating role in the influence of subjective norms on behavioral intention through safety attitude. The results show that subjective norm affects the behavioral intention directly through behavior attitude, and it can also positively affect the behavioral intention directly, with the largest path coefficient value and the highest influence degree (the influence coefficient is 0.81). Subjective norms embody the constraints by the external entities of the enterprise on work safety, which involves regulatory constraints from the government (hard norms), safety demands from corporate employees (Liu et al., 2019), public opinion pressure, the binding force of industry associations, and the work safety constraints of upstream and downstream enterprises in the supply chain (soft constraints). These factors present standard requirements for the work safety behavior and behavioral intentions of MSEs in high-risk industries.

(3) Work safety perceptual behavioral control (PBC) positively affects behavioral intention (I), and they are significantly correlated with each other (path coefficient is 0.411). Perceptual behavior control is an effective resource supply for work safety behavior. Validity analysis identifies three common factors, namely, internal resources of the enterprise (PBCCF1), support of service organizations (PBCCF2), and government support (PBCCF3). The internal resources of the enterprise include the management level of the enterprise, the safe operation capability of the employees, and the work safety software and hardware resources invested. The support of service organizations includes technical support such as work safety training, standardized guidance, and daily supervision provided to MSEs. Government support policies are the support resources provided by the government such as services and subsidies. Combined with the results of EFA, it is found that the eigenvalue and explained variance of the enterprise internal resources (PBCCF1) are significantly higher than that of support of service organizations and government support. Therefore, improving the effective resources, especially the internal resources of the enterprise, is of great significance in enhancing the behavioral intention of work safety.

(4) Work safety behavior habit (BH) is not significantly related with the behavioral intention (I). The test results are similar to the empirical research results by foreign scholars (research on the field of risk behavior), that is, the direct effect of behavior habits on behavioral intentions is not obvious. After the validity analysis, the behavior habits identify two common factors, the past behavior of the enterprise (BHCF1) and the code of conduct of neighboring enterprises (BHCF2). The past behavior of the enterprise reflects the past behavior formed in the long-term production, that is, the illegal operations that the enterprise will still implement as long as no accident occurs (Norman and Cooper, 2010). The code of conduct of neighboring enterprises reflects the work safety habits

and investment in the safety of neighboring enterprises. Combined with the results of the EFA on behavioral habits, the eigenvalues and explanatory variances of past behaviors of enterprises are significantly higher than those of the code of conduct of neighboring enterprises. It can be seen that the illegal production behaviors formed over a long period of time directly affect their work safety behavior attitudes, thereby determining their behavioral intentions. The behavioral habit does not directly affect the behavioral intention, which can be reflected from the mediating role of the behavioral attitude in hypothesis 6.

(5) Work safety behavior attitude (A) plays a mediating role in the influence of behavior habit (BH) on behavioral intention (I). Combined with the conclusion of hypothesis 5, the behavior habit does not directly affect behavioral intentions (Ma et al., 2016) but influences behavioral intentions through the mediating effect of behavioral attitudes. The results show that behavior habits significantly and positively affect behavior attitudes (the path coefficient is 0.486). It implies that in the past, the convenience brought by some unsafe behaviors to the production of enterprises leads to the reduction of individuals' awareness of the danger of unsafe production behaviors. The demonstration effect of work safety of neighboring enterprises also stimulates the investment in work safety of the enterprise, greatly affecting its work safety behavior. It is easier to change business owners' behavior attitudes through the standardization of the behavioral habits of MSEs in high-risk industries, especially their past behaviors, and their safety awareness can be enhanced.

(6) Work safety risk consciousness (RC) significantly influences the behavioral intention (I), but the influence degree is the lowest (the path coefficient is –0.289). Risk consciousness is negatively correlated with behavioral intention. This result shows that enterprises with higher risk preferences are more likely to conduct unsafe production behaviors. The risk consciousness variable is taken as an exogenous variable supplemented in TPB theory. The path coefficient shows that it has the weakest influence on the behavioral intention of work safety. However, the introduction of it can improve the explanatory power of the work safety behavior model of MSEs in high-risk industries to a certain extent, and the problem is explained more comprehensively and sufficiently. In the research on the work safety behavior of MSEs in the high-risk industries, risk-conscious behaviors are more likely to form unsafe behavioral intentions (Tucker and Turner, 2013), causing work unsafe behaviors. It is suitable for this variable to be a supplement to TPB theory.

(7) Work safety behavioral intention (I) significantly influences the safety behavior (B), and they are significantly correlated with each other (the path coefficient is 0.457). After the validity analysis, three common factors are identified by safety behaviors, namely, safety management (BCF1), safety training (BCF2), and safety prevention (BCF3). These three aspects are well developed in work safety behavior and are recognized by scholars (Lu et al., 2016). Combined with EFA of behavior, it is found that the eigenvalues and explanatory variances of the three common factors are relatively close, and the safety training value is slightly higher. It shows that the behavioral intention of work safety affects the safety management, safety training, and safety prevention of the enterprise. The behavioral intention of MSE's owners influences the work safety behaviors of MSEs through the decision of the business owner to realize the work safety behavior of MSEs.

DISCUSSION

Theoretical Significance

Considering the risk characteristics of MSEs in high-risk industries, we study the work safety attitude of MSE's owners with decision-making power, and then we expand the traditional TPB model. Under the joint action of MSEs in high-risk industries, government safety supervision department, work safety service agencies, and related subjects of social sanction, it is studied the different factors affect the work safety behavior of MSEs. It reduces the influence mechanism of work safety behavior of MSEs in high-risk industries and further identifies the key factors affecting the formation of work safety behavior.

(1) From the perspective of MSEs, there are many factors for the work safety behavior of MSEs in high-risk industries. The key factors are the work safety attitude of the business owner, the enterprise work safety resources, the risk consciousness, and the past behavior of the enterprise. These factors determine the behavioral intention and further determine the work safety behavior. According to the influence degree, the most important factor is the work safety attitude of the business owner, followed by the enterprise work safety resources.

(2) From the perspective of the government safety supervision department, it is studied the influence of daily supervision, penalties for violations, accountability, and penalty for accidents, purchasing the services of the qualified enterprises, providing subsidies and rewards by the government on enterprise behavioral intentions. The key factors are government supervision, government punishment, and government subsidies.

(3) From the perspective of work safety service agencies, it is explored the influence of the technical support and supervision and management provided for MSEs that purchase entrusted business by service organizations on behavioral intentions. It can be seen that work safety service level (focus on technology and supervision) is the key factor.

(4) From the perspective of social sanction, it involves the work safety constraints of public opinion, industry

associations, and upstream and downstream enterprises in the supply chain of MSEs. The influence of neighboring enterprises on the behavior habits of small and micro enterprises is considered. The factors influence behavioral intentions, and different enterprise behaviors are formed. The key factors are social constraints and influence of neighbor enterprise behavior.

Hence, the influence mechanism of work safety behaviors of MSEs in high-risk industries is obtained, as shown in **Figure 4**.

Practical Significance

The influencing mechanism and path of work safety behavior of MSEs in high-risk industries are analyzed, and the key influencing factors of work safety behavior of MSEs are revealed. It is further explored how to improve the awareness of work safety, stimulate the internal drive of work safety, and guide the transformation of work safety behavior of MSEs from a negative response to positive pursuit.

(1) It is a fundamental way to reduce the work unsafe behavior of MSEs by changing the behavior attitude of the enterprise owners, which directly affects the intention of work safety behavior.
(2) It is a basic guarantee to realize the work safety behavior of MSEs by effective resource supply for work safety behavior of MSEs. It positively affects the intention of work safety behavior from three dimensions, namely, internal strength resources, service organization support resources, and government support resources. In particular, the internal strength resources of enterprises play a major role in the promotion of work safety behavior.
(3) The behavior habits in high-risk industries formed by enterprises for a long time has a direct effect on the behavior attitude of enterprises toward work safety, which acts on the behavioral intentions through the intermediary function of behavior attitude. Enterprises with strong risk preferences are more likely to have the tendency of work unsafety behavior.
(4) Subjective norms mainly come from the government safety supervision departments, work safety service agencies, and social sanctions. Subjective norms have a direct impact on behavioral intention and play an intermediary role. Its overall impaction is the greatest.

It can be seen that the four key factors affecting the work safety behavior of MSEs in high-risk industries are the strength of enterprise work safety resources, the supervision of the government safety supervision department, the degree of government service subsidies, and the service level of work safety service agencies.

Limitations and Future Work

When conducting empirical analysis based on the theory of planned behavior, it is necessary to conduct a questionnaire survey on the business owners of MSEs in high-risk industries in China. Affected by the epidemic, it is only investigated the provinces in the east of China, involving MSEs' owners in high-risk industries such as machinery manufacturing, constructional engineering, production and storage of hazardous material, transportation, non-coal mining, fireworks production, and metallurgy. There is little research on provinces with relatively backward economic development in China. In addition, the exploitation of small coal mines has been banned as early as 2005 in some provinces in the east of China (such as Jiangsu Province). Therefore, the interviewees and questionnaires in this study do not involve industries in areas with a high incidence of work safety accidents and the hardest-hit areas. The study on high-risk industries such as coal production, research, production, and testing of weapons and equipment (including civil aviation and nuclear fuel) has a positive guiding role and practical significance for enriching and enhancing the work safety behavior of MSEs. We will conduct an in-depth research on it when conditions and resources are sufficient in the future.

CONCLUSION

It is pointed out that "the lucky psychology + the limited resource" is the root of the passive work safety behavior of MSEs in high-risk industries. The work safety behavior of MSEs is affected by the joint action from MSEs, government safety supervision departments, work safety service agencies, and social sanctions. We should strengthen the government supervision, punishment, and subsidies; seek the service support of work safety service agencies; and enlarge the control of constraints from society. Only in this way, the enterprises could reduce the work unsafety behavior of MSEs as far as possible. We should stimulate the internal driving force of work safety behavior and ensure the safe production capacity of MSEs, which will improve the overall work safety level of MSEs in high-risk industries.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Review Committee of Jiangsu University in China. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

WL and SL investigated the data and carried out the project administration. XN and XZ carried out the data curation. WL and XN carried out the formal analysis. QM carried out the funding acquisition and supervised the data. WL performed the methodology, carried out the resources, and wrote the manuscript. XN validated the data. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.880205/full#supplementary-material

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Evolutionary Game Analysis of Construction Workers' Unsafe Behaviors Based on Incentive and Punishment Mechanisms

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Construction is one of the most dangerous industries because of its open working environment and risky construction conditions. In the process of construction, risk events cause great losses for owners and workers. Most of the risk events are closely related to unsafe behaviors of workers. Therefore, it is of great significance for contractors to establish management measures, e.g., incentive and punishment mechanism, to induce workers to reduce unsafe behaviors. This paper aims to take the incentive and punishment mechanism into consideration and develop an evolutionary game model to improve the effectiveness of safety management. The evolutionary stability strategies which can help reduce unsafe behaviors are obtained and analyzed. Results show that there are 12 equilibrium strategies under the condition of different parameters. Specifically, the incentive and punishment mechanism has played an important role for the evolution direction. A balanced incentive and punishment mechanism for the investment and positive stimulus for workers can effectively promote both sides to take positive behaviors, and then realize good evolutionary stable situations. In addition, the initial perceptions of both sides have a decisive impact on the evolution direction. Strengthening communication with the mutual trust between both sides can improve safety performance of both sides. This study is valuable for contractors to design appropriate incentive and punishment measures and establish relevant strategies to promote safe behaviors of construction workers.

Keywords: construction workers, unsafe behavior, mechanism design, evolutionary game, incentive and penalty

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INTRODUCTION

The global construction industry has maintained a rapid growth in the past decades. Taking China as an example, the total output value of the construction industry has increased from 13.7 trillion RMB to 29.3 trillion RMB in the past decade (2012–2021), accounting for about 25% of the total GDP for a long time. Thus, the construction industry is a driving force of national economy. Compared with the manufacturing industry, the working environment of the construction industry is more open with complex construction site conditions. During the construction process, the main structure of the building is constantly changing with a large number of temporary construction facilities. These adverse factors contribute to on-site risks frequently (Moosa and Oriet, 2021).

Therefore, safety management is a core management problem on site. The evidence from Hong Kong shows that 80% of industrial accidents occur in the construction field (Labor Department, 2021). According to data of China Ministry of Housing and Urban-rural Development, safety accidents related to the production of housing and municipal engineering led to 840 and 904 deaths in 2018 and 2019 respectively (Standardization of Engineering Construction., 2020). The safety situation in the construction industry is an on-going concern.

Various causes can lead to construction accidents, and unsafe behaviors of workers are considered to be one of the important sources (Guo et al., 2018; Inyeneobong and Boluwatife, 2022). Unsafe behaviors of workers mean that their behaviors deviate from safe procedures (Shin et al., 2014). Several factors contribute to unsafe behaviors (Su et al., 2019). For example, Fang et al. (2015) found that the accumulation of fatigue would significantly reduce workers' control abilities. Man et al. (2021) studied the influence mechanism of individual and organizational factors on risk-taking behaviors of workers. Jiang et al. (2015) identified the personal, environmental and organizational conditions which affected affect workers' behaviors through cognitive analysis and established a system dynamics model to explain how it affect these behaviors. Cheng et al. (2022) provided a systemic review of the application of electroencephalogram in computing construction workers' cognitive statuses which affect their safety and productivity. Xia et al. (2020) formed the antecedent model of worker's unsafe behaviors through the literature review of empirical research and the model included 83 factors which were divided into 5 groups.

It can be found from the accident records in construction industry that numerous safety accidents or accident symptoms have occurred due to mistakes or the negligence of managers (Teo et al., 2005; Huang and Hinze, 2006). Safety management is one of the most important factors to promote the implementation of safety measures and workers' occupational safety, which significantly affect unsafe behaviors. According to a survey of a construction for affordable housing in Nanjing which is located in eastern China, contractors set up safe construction awards regularly, and punished workers for unsafe behaviors, including smoking, not wearing hard hats, etc. Contractors were also actively exploring the use of closed circuit video equipment and artificial intelligence to reduce the cost of monitoring workers' unsafe behaviors and improve effectiveness. Many scholars have researched on safety management. Lu and Yang (2010) and Mearns and Reader (2008) found that safety policies and concerns could positively influence workers' behaviors by collecting survey statistics from workers. Jiang et al. (2014) concluded that punishment was the most effective method of correcting workers' mistakes by means of modeling workers' safe behaviors and testing the impact of incentive measures on workers' behaviors. Haas (2020) pointed out that when safe objectives of the organizer conflicted with production objectives, workers tend to ignore work safety, which led to ineffectiveness of safe incentives. Zhou et al. (2011) concluded that the safe awareness of workers could be improved with a safe environment which has safety regulations, trainings and publicity. Sparer and Dennerlein (2013) collected the safety inspection data of 19 construction projects owned by Harvard University to calculate the frequency and distribution in the incentive plan every month and designed a safety incentive plan to ensure fairness and competitiveness. Ji et al. (2021) researched the tournament incentive mechanism of construction workers' safety behavior with considering multiple heterogeneity and found workers with a risk aversion attitude and a higher level of fairness preference need higher incentive. However, high incentives from managers would only improve workers' safety performance in the short term with its decreased value and shortening the time interval between incentives is more beneficial to promote safe performance (Ghasemi et al., 2015). Generally speaking, safety management has a significant impact on the unsafe behavior of workers, and the incentive and punishment mechanism is an important stimulus. However, most of the above literatures analyzed the impact mechanism of safety management measures such as incentives, and most of them were qualitative. There is a lack of theoretical research on workers' behavioral decisions under incentive or punishment safety management strategies.

While the above studies confirm the necessity of extended and wellplanned management measures to improve safety, the responses of workers to these management strategies, including their learning and evolutionary behaviors should not be ignored. According to social learning theories, human learning includes two types of behavior, one is personal learning, which changes behavior through constant trial and error, and the other one is social learning, which alters its own behavior by imitating others (Mesoudi, 2011).

This study employs the evolutionary game method in order to analyze the evolutionary behavior caused by changing one's own strategies due to learning. The game theory, originated from the theory of biological evolution, is a group behavior analysis theory based on the framework of bounded rationality. It can be described as a mathematical model of strategic interaction between independent subjects. Effective solutions are likely to be determined through the simulation and analysis of the situation in the model so as to provide participants with the best decision-making strategy (Brickley et al., 2000). Smith and Price (1973) established the evolutionary stability strategy, which reflected the dynamic balance of the game behavior of bounded rational groups more accurately. Nowadays, scholars have adopted the game theory in many fields to study the decision-making and evolutionary problems including interactive strategies (Ji et al., 2021). For example, Meng et al. (2021) analyzed the game behaviors of the government and contractors under four different bonus and penalty strategies in green building projects, and then discovered that dynamic incentives as well as static punishments were the best strategies for contractors to promote projects. Song et al. (2021) suggested that the interests and costs of users should be taken into account in the decision-making stage after analyzing the tripartite game among users, public sectors and private sectors in user paid PPP projects. Lv et al. (2021) investigated the evolution of concession renegotiation behaviors when the actual flow in PPP transportation project was inconsistent with the expected flow through evolutionary game, which provides decision support for the governance of concession renegotiation behaviors in PPP projects. Loghman et al. (2022) established a mixed-integer programming model consisting of game theory and project schedule to reduce the duration of grand infrastructure projects with a minimum increase in cost. Luo et al. (2021) used a cooperative game theory to determine the optimal distributed photovoltaic system operation strategy with a benefit analysis to promote the low-carbon economy. Fang and Ding (2009) established a game model among miners, regulatory authorities and coal factories with the analysis of the related safety management, and then made suggestions about the safety management. Yang and Wang (2022) built a three-party game model by investigating the relationships among construction supervision units, construction enterprises and workers, and then concluded that increasing the punishment for violations of workers as well as increasing the benefits and incentives for operations in accordance with regulations would promote behaviors of workers. Wang et al. (2016) employed the game theory to research on the willingness of workers in specific groups to participate in the safety management and found that the willingness of workers to participate in the safety management could be realized by improving workers' rational cognitions of the investment benefits from safe behaviors. These studies have proved that the evolutionary game can be effective in studying the strategic interaction between two parties.

This paper considers that contractors have established both incentive and penalty measures. In view of the long-term nature of safety management, contractors and workers will adjust their strategies through learning by comparing incentive and penalty measures during the progress of the project. This paper aims to: (1) establish an evolutionary game model to investigate the relationship between contractors' active and passive supervision strategies and workers' safe and unsafe behaviors; (2) examine the evolutionary stability of strategies, which represent the equilibrium state of the system after a long interaction from both contractors' and workers' point of view. (3) demonstrate the effectiveness of the model in finding optimal parameter settings in a few scenarios. This paper is organized by the below structure. This paper begins with assumptions about the income of contractors and workers and then forms the payment matrix of both parties. Based on the research method of the evolutionary game, the evolutionary stability of the strategies from both sides is investigated. This paper then develops the scenarios under diverse conditions according to the analysis results of the evolutionary stability for classifications, and the management significance of the scenarios is discussed. With the sensitivity analysis of parameters, the impacts of initial strategies and parameters on evolutionary directions are analyzed respectively. Finally, a summary is given on account of the results of this study.

MODEL ESTABLISHMENT AND ANALYSIS

Assumptions and Parameters

In this paper, there are two parties, contractors and construction workers, in the safety management process. Contractors can adopt active supervision or passive supervision. When contractors adopt active supervision to reduce safe incidents, more resources are devoted to the safety management, such as worker safety training and security equipment. The construction workers can adopt safe behaviors or unsafe behaviors. When workers adopt safe behaviors, workers need to improve security awareness through safety training and cooperate with the contractor's regulations to adopt safe measures positively. It is assumed that the occurrence of risk events has a certain probability and is directly related to unsafe behaviors of construction workers. When construction workers have unsafe behaviors, risk events have great potential to happen. Contractors need to establish incentive and penalty measures for behavioral change of workers. Contractors will be punished by government for workers' unsafe behaviors which are periodically inspected. As a result, contractors have intrinsic motivations to improve their corporate reputations.

It is further assumed that if a risk event occurs, there will be a loss of "L." The occurrence of the risk events is related to the behavior strategies adopted by the workers. When workers demonstrate safe behaviors, the probability of occurrence is "p_1." When workers demonstrate unsafe behaviors, the probability of occurrence is "p_2," and obviously in near all construction projects, "p_1" < "p_2." Contractors and construction workers have different perception related to the coefficients of loss, which are "α" and "β" respectively. When contractors adopt a passive supervision strategy, the behavioral characteristics of workers can be observed under a certain incentive "R" and a punishment "G." On the other hand, if an active supervision strategy is selected, contractors pay the supervision cost of "C_1" and workers will pay the cost of "C_2" to correct their behaviors. When both parties adopt active strategies at the same time, contractors will receive the reputational income "F" for enhanced corporate reputations and social responsibilities. If unsafe behaviors of workers are identified by the government, contractors will receive

TABLE 1 | Main parameters and descriptions.

Parameters	Descriptions
L	The loss due to risk events
p_1	Probability of risk events when construction workers take safe behavior strategy
p_2	Probability of risk events when construction workers take unsafe behavior strategy
α	Contractors' perception on the coefficient of risk loss
β	Workers' perception on the coefficient of risk loss
R	If workers take safe behavior strategy, contractors give incentive to workers
G	If workers take unsafe behavior strategy, contractors impose a penalty on workers
C_1	The supervision cost of contractors under active supervision
C_2	The cost of workers to take safe behaviors under active supervision
F	Reputation income of contractors
Q_1	The government imposes fine on contractors because of workers' unsafe behaviors under active supervision
Q_2	The government imposes fine on contractors because of the workers' unsafe behaviors under passive supervision

TABLE 2 | The payoffs matrix of contractors and construction workers.

		Construction workers	
		Safe behavior	**Unsafe behavior**
Contractors	Active supervision	$-\alpha p_1L - R - C_1 + F$ $-\beta p_1L + R - C_2$	$-\alpha p_2L + G - C_1 - Q_1$ $-\beta p_2L - G$
	Passive supervision	$-\alpha p_1L$ $-\beta p_1L - C_2$	$-\alpha p_2L - Q_2$ $-\beta p_2L$

corresponding penalties. The severity of the penalty varies, depending on whether the contractors take an active supervision strategy or not. If contractors take active supervision strategy, the penalty is "Q_1." Otherwise, the penalty is "Q_2," and obviously, "Q_1" < "Q_2." The model parameters and variables are listed in **Table 1**.

The game payoffs matrix of contractors and construction workers can therefore be constructed, as shown in **Table 2**.

Solution and Analysis of Evolutionary Stability Strategy

Assuming that the probability of contractors adopting an active supervision strategy is x, therefore the probability of adopting a passive supervision strategy is $1 - x$. The probability of construction workers adopting a safe behavior strategy is y, and the probability of adopting an unsafe behavior strategy is $1 - y$.

The expected revenue under the condition of an active supervision or a passive supervision are w_{1p}, w_{1n} and its mean average for contractors is w_1. They can be calculated as follows:

$$w_{1p} = y\left(-\alpha p_1 L - R - C_1 + F\right) + \left(1-y\right)\left(-\alpha p_2 L + G - C_1 - Q_1\right) \quad (1)$$

$$w_{1n} = y\left(-\alpha p_1 L\right) + \left(1-y\right)\left(-\alpha p_2 L - Q_2\right) \quad (2)$$

$$w_1 = xw_{1p} + (1-x)\,w_{1n} = x(y\,(-R - G + Q_1 - Q_2 + F) + G - C_1 - Q_1 + Q_2) + y\left(\alpha(p_2 - p_1)L + Q_2\right) - \alpha p_2 L - Q_2 \quad (3)$$

The expected revenue under the condition of safe behaviors and unsafe behaviors are w_{2s},w_{2u} and its mean average for construction workers is w_2. They can be calculated as follows:

$$w_{2s} = x\left(-\beta p_1 L + R - C_2\right) + (1-x)\left(-\beta p_1 L - C_2\right) \quad (4)$$

$$w_{2u} = x\left(-\beta p_2 L - G\right) + (1-x)\left(-\beta p_2 L\right) \quad (5)$$

$$w_2 = yw_{2s} + \left(1-y\right) w_{2u} = y(x\,(R+G) + \beta(p_2 - p_1)L - C_2) + x\,(-G) - \beta p_2 L \quad (6)$$

According to the theory of evolutionary game (Swinkels, 1993), the replicated dynamic equations of contractors and construction workers can be obtained as follow. For the convenience of calculation, let $Q_2 - Q_1 = \Delta Q$.

$$F(x) = \frac{dx}{dt} = x\left(w_{1p} - w_1\right) = x\,(1-x)\,[y\,(-R - G - \Delta Q + F) + G - C_1 + \Delta Q] \quad (7)$$

$$G\left(y\right) = \frac{dy}{dt} = y\,(w_{2s} - w_2) = y\left(1-y\right)[x\,(R+G) + \beta(p_2 - p_1)L - C_2] \quad (8)$$

The corresponding Jacobi matrix is:

$$J = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad (9)$$

Corresponding:

$$a_{11} = (1-2x)\,[y\,(-R - G - \Delta Q + F) + G - C_1 + \Delta Q] \quad (10)$$

$$a_{12} = x\,(1-x)\,(-R - G - \Delta Q + F) \quad (11)$$

$$a_{21} = y\left(1-y\right)(R+G) \quad (12)$$

$$a_{22} = \left(1-2y\right)[x\,(R+G) + \beta(p_2 - p_1)L - C_2] \quad (13)$$

The trace of the Jacobi matrix can be obtained by solving (14):

$$Tr\,J = (1-2x)\left[y\,(F - R - G - Q) + G - C_1 + Q\right] + \left(1-2y\right)[x\,(R+G) + \beta(p_2 - p_1)L - C_2] \quad (14)$$

The determinant of Jacobi matrix can be obtained by solving (15):

$$Det\,J = (1-2x)\left[y\,(F - R - G - \Delta Q) + G - C_1 + \Delta Q\right]\left(1-2y\right)[x\,(R+G) + \beta(p_2 - p_1)L - C_2] - x\,(1-x)\,(F - R - G - \Delta Q)\,y\left(1-y\right)(R+G) \quad (15)$$

According to the replicated dynamic equations of contractors and construction workers, there are five equilibrium points. These five equilibrium points are (0,0), (0,1), (1,0), (1,1) and (x^*, y^*),with:

$$x^* = \frac{C_2 - \beta(p_2 - p_1)L}{R+G} \quad (16)$$

$$y^* = \frac{C_1 - G - \Delta Q}{F - R - G - \Delta Q} \quad (17)$$

Among these five equilibrium points, (0,0) represents that the contractors take the passive supervision while the construction workers take the unsafe behaviors. (0,1) represents that the contractors take passive supervision while the construction worker adopts safe behaviors. (1,0) represents that contractors take the active supervision while construction workers take unsafe behaviors. (1,1) represents that contractors take the active supervision while the construction workers take safe behaviors. And (x^*, y^*) represents that both contractors and construction workers take the mixed strategies, that is, both positive and negative strategies exist. The determinant and trace of the Jacobi matrix at different equilibrium point are shown in **Table 3**.

Under the evolutionarily stable strategy, neither contractor nor construction workers can achieve greater benefits by changing their own strategies, thus resulting in a stable state of strategies for both parties. According to evolutionary stability, the evolutionary states of each point are saddle point, instability points and evolutionary stable strategy (ESS) respectively when the value and trace of each equilibrium point are $(-, N)$, $(+, +)$ and $(+, -)$. According to the assumptions in this paper, different parameter ranges are calculated separately, and 12 evolutionary stability scenarios are obtained and shown in **Appendix 1**.

SCENARIO ANALYSIS

Based on the above analysis process, there are 12 evolutionary stable scenarios for contractors and workers. Considering the fact that supervision cost is the main factor preventing contractors from adopting the active supervision strategies to improve safety performance, this study further categorizes the 12 scenarios into three categories based on the costs to contractors. The first category reflects that supervision cost of contractors is lower than the sum of punishment fees from both workers and the government as well as the differences between potential income brought by reputation and incentive investment, i.e., $C_1 < \min\{G + \Delta Q, F - R\}$. There are three scenarios when the contractors have a strong motivation to take active supervision. By considering the parameters under the corresponding restrictions, the evolution scenarios are shown in **Figure 1**. The second category reflects that supervision cost of contractors is greater than the sum of punishment fees from both workers and the government as well as the differences between potential income brought by reputation and incentive investment, i.e., $C_1 > \min\{G + \Delta Q, F - R\}$. There are three scenarios when the contractors have to pay a high supervision cost, which are shown in **Figure 2**. The third category reflects that supervision cost is between the sum of punishment fees from both workers and the government and the differences between potential income brought by reputation and incentive investment, i.e., $\min\{G + \Delta Q, F - R\} < C_1 < max\{G + \Delta Q, F - R\}$. In this condition, the strategies of contractors are uncertain and it has six scenarios, which is shown in **Figures 3**, **4**.

TABLE 3 | The determinant and trace of the Jacobi matrix at different equilibrium point.

Equilibrium point	*Det J*	*Tr J*
(0,0)	$(G - C_1 + \Delta Q)^*[\beta(p_2 - p_1)L - C_2]$	$G - C_1 + \Delta Q + \beta(p_2 - p_1)L - C_2$
(1,0)	$-(G - C_1 + \Delta Q)^*[(R + G) + \beta(p_2 - p_1)L - C_2]$	$C_1 - \Delta Q + R + \beta(p_2 - p_1)L - C_2$
(0,1)	$(F - R - C_1)^* - [\beta(p_2 - p_1)L - C_2]$	$(F - R - C_1) - [\beta(p_2 - p_1)L - C_2]$
(1,1)	$(F - R - C_1)[(R + G) + \beta(p_2 - p_1)L - C_2]$	$-F + C_1 - G - \beta(p_2 - p_1)L + C_2$
(x^*, y^*)		0

Category 1: Supervision Cost of Contractors Is low

Conclusion 1: When the supervision cost is low, that is $C_1 < min\{G + \Delta Q, F - R\}$, there will be three evolutionary situations and two evolutionary stable states, depending on the cost of construction workers to take safe behaviors. When $C_2 > (R + G) + \beta(p_2 - p_1)L$, the ESS of the system is (1,0). When $C_2 < (R + G) + \beta(p_2 - p_1)L$, the evolution trend of the system is slightly different in two cases, but it finally levels off at (1,1). These three scenarios are shown in **Figures 1A–C** respectively. The horizontal axis represents the percentage of contractors using the active supervision strategy and the vertical axis represents the percentage of construction workers taking safe behaviors in **Figure 1**, the same in **Figures 2–4**.

Managerial implications of Conclusion 1. Conclusion 1 demonstrates a situation when the supervision cost is lower than the sum of punishment fees from both workers and the government as well as the differences between potential income brought by enhanced reputation and incentive investment. Under this situation, the system will evolve in a positive direction when the cost of workers to take safe behaviors is

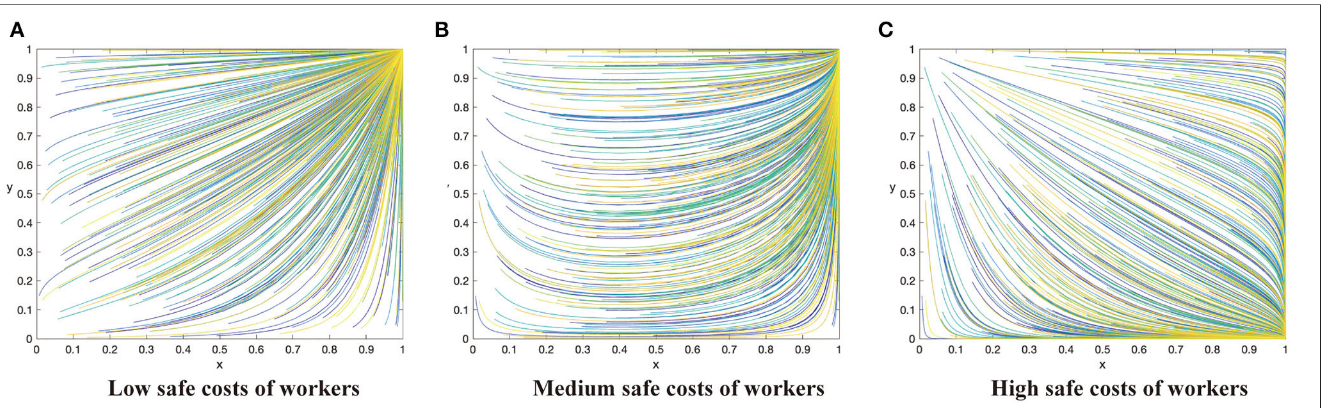

FIGURE 1 | The dynamic evolutionary path of the game in category 1, including low safety costs to workers **(A)**, high safety costs to workers **(C)**, and medium safety costs to workers **(B)**.

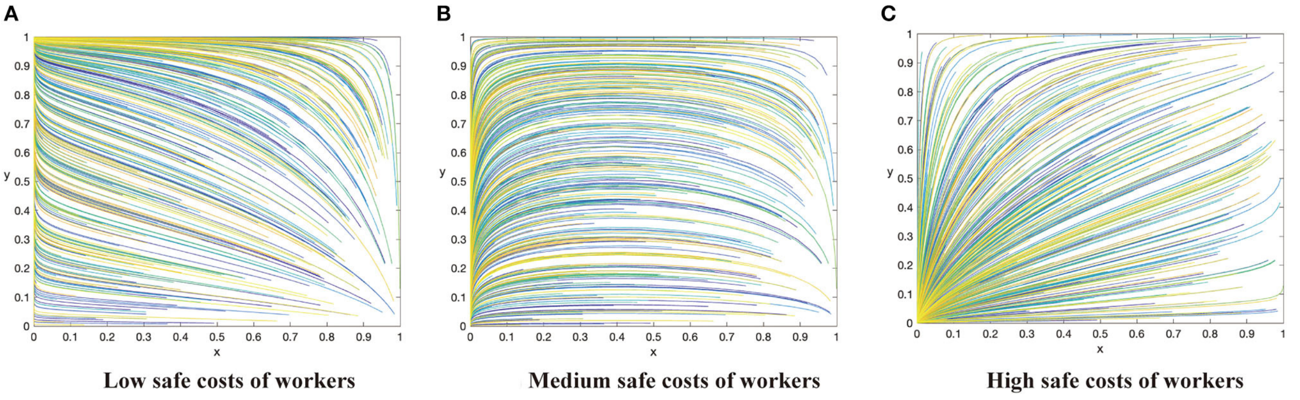

FIGURE 2 | The dynamic evolutionary path of the game in category 2, including low safety costs to workers **(A)**, high safety costs to workers **(C)**, and medium safety costs to workers **(B)**.

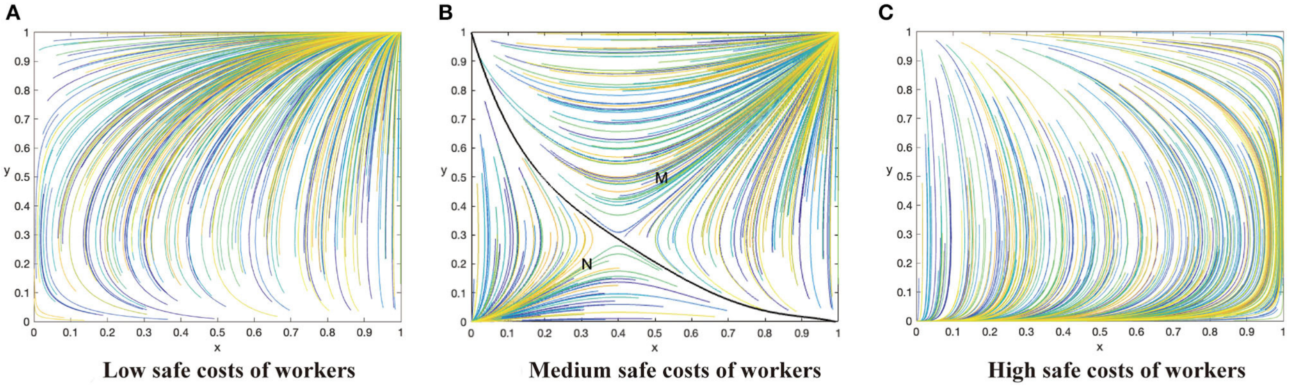

FIGURE 3 | The dynamic evolutionary path of the game in sub-category 3-1, including low safety costs to workers **(A)**, high safety costs to workers **(C)**, and medium safety costs to workers **(B)**.

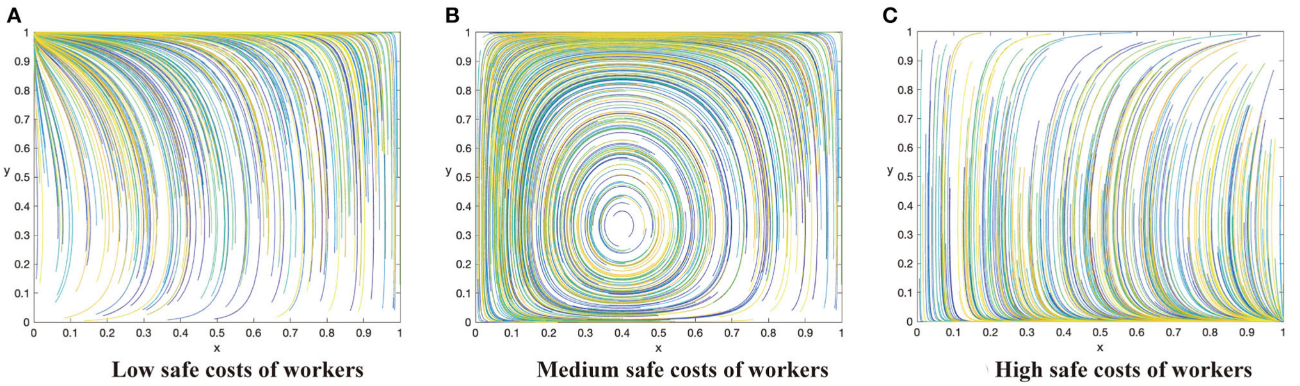

FIGURE 4 | The dynamic evolutionary path of the game in sub-category 3-2, including low safety costs to workers **(A)**, high safety costs to workers **(C)**, and medium safety costs to workers **(B)**.

relatively low. In the two sub-categories above (**Figures 1A,B**), construction workers will evolve to take safe behaviors if the cost of workers is less than $\beta(p_2 - p_1)L$, which is the utility improvement brought by safe behaviors. When the populations of contractors adopting positive supervision strategy is low, construction workers evolve in the direction of taking unsafe behaviors. On the other hand, with the number of contractors adopting positive supervision strategy increases, the evolution direction of construction workers is to take safe behaviors, and finally the system evolves in a positive direction. The groups of contractors and workers tend to achieve stability at (1,1) respectively in the end. If the effort cost of workers further increases, the effort strategy employed by construction workers will not pay off. Under this situation, although the contractors evolve in the direction of active supervision (i.e., by paying more in active supervision), they exert not enough influence on construction workers to change their behaviors (i.e., evolution trend). Both parties achieve a stable state in (1,0) finally (**Figure 1C**).

Category 2: Supervision Cost of Contractors Is High

Conclusion 2: When the supervision cost is high, that is $C_1 > max\{G + \Delta Q,\ F - R\}$, there will be three evolutionary situations and two evolutionary stable states based on the value of safety costs to construction workers. When $C_2 < \beta(p_2 - p_1)L$, the ESS of the system is (0,1). When $C_2 > \beta(p_2 - p_1)L$, the evolution trend of the system is slightly different in two cases, but it is stable at (0,0) finally. All these are shown in **Figures 2A–C** respectively.

Managerial implications of Conclusion 2. Conclusion 2 demonstrates a situation when the supervision cost is higher than the sum of punishment fees from both workers and the government as well as the differences between potential income brought by enhanced reputation and incentive investment. Under this situation, the system will evolve in a negative direction when the cost of workers is relatively high. In the two sub-categories above (**Figures 2B,C**), construction workers will evolve to take unsafe behaviors if the cost of workers is greater than the utility improvement brought by safe behaviors. With the number of contractors adopting positive supervision strategy decreasing, the evolution direction of construction worker populations is to take safe behaviors, and finally the system evolves in a negative direction. In the two sub-categories above (**Figures 2B,C**), contractors and workers will finally achieve stability at (0,0). If the cost to construction workers is further reduced, and the utility improvement brought by safe behaviors can offset the effort cost completely, both sides achieve a stable state at (0,1) (**Figure 2A**).

Category 3: Supervision Cost of Contractors Is in the Middle

When the supervision cost is in the middle, the evolution direction of the system will be divided into two scenarios. The first sub situation is $F > G + \Delta Q + R$ where the corporate social responsibility perception is relatively larger. Enterprises are willing to establish a positive corporate image and avoid workplace casualties as much as possible, which is common for large enterprises and state-owned enterprises. The other scenario is $F < G + \Delta Q + R$, when the benefit of building a reputation is relatively lower.

Sub-category 3-1: The Benefits of Corporate Social Responsibility Perceptions Are of Great Value

Conclusion 3: When the supervision cost is in the middle state, that is $G + \Delta Q < C_1 < F - R$, there will be three evolutionary situations and three evolutionary stable states based on the value of safety costs to workers. When $C_2 < \beta(p_2 - p_1)L$, the ESS of the system is (1,1). When $\beta(p_2 - p_1)L < C_2 < (R + G) + \beta(p_2 - p_1)L$, the system has two ESS (0,0) and (1,1). When $C_2\ (R + G) + \beta(p_2 - p_1)L$, the ESS of the system is (0,0). All these are shown in **Figure 3**.

Managerial implications of Conclusion 3. Conclusion 3 demonstrates a situation when the supervision cost is in the middle between the potential benefit and the cost of taking active supervision. The system has a relatively diverse evolutionary stable state. The system will be stable at (0,0) when the cost of construction workers is greater than the utility improvement combined with incentives and punishments brought by taking safe behaviors (**Figure 3C**). As the costs to workers increase, the system will eventually evolve in the negative direction although the evolution trend of contractors is positive for a time. If the cost to construction workers decreases slightly, but is not lower than the utility improvement brought by taking safe actions, two ESSs will appear in the system. At this time, the evolution direction depends on the initial state of the system. The system will evolve toward (1,1) if the mixed strategies of the contractors and workers are transferred to area M (the bottom left area of **Figure 3B**), while the system will evolve toward (0,0) if the mixed strategies of contractors and workers are transferred to area N (the upper right area of **Figure 3B**). A mixed strategy is one where contractors and construction workers will randomly choose their strategies with some probability. Whether contractors and works have a positive attitude at the beginning is very significant to determine the evolution direction of the system, so contractors can strengthen mutual trust and cooperation to promote the evolution positively. The area M represents the probability that the two sides will active strategies which is related to (x^*, y^*). When the cost to workers is lower than the utility improvement brought by safe behaviors, the effort cost can be offset completely, therefore the system will evolve toward (1,1). With the number of construction workers taking safe behaviors increases, the evolution direction of groups of contractors is to take active supervision. Finally, both parties obtain a stable state at (1,1) (**Figure 3A**).

Sub-category 3-2: The Benefits of Corporate Social Responsibility Perceptions Are of Small Value

Conclusion 4: When the supervision cost is in the middle state, that is $G + \Delta Q < C_1 < F - R$, there will e three evolutionary situations and three evolutionary stable states based on the value of safety cost to construction workers. When $C_2 < \beta(p_2 - p_1)L$, the ESS of the system is (0,1). When $\beta(p_2 - p_1)L < C_2 < (R + G) + \beta(p_2 - p_1)L$, there will be only hybrid strategies and no evolutionary stable point ESS. When $C_2\ (R + G) + \beta(p_2 - p_1)L$, the ESS of the system is (1,0). The three scenarios are shown in **Figures 4A–C** respectively.

Managerial implications of Conclusion 4. Conclusion 4 demonstrates a situation when the supervision cost is in the middle between the potential benefit and the cost of taking active supervision, which is similar to Conclusion 3, but in this case the potential benefits of improved reputation is low. The system will be stable at (1,0) when the cost of workers is greater than the utility improvement combined with incentives and punishments brought by safe behaviors (**Figure 4C**). Contractors will involve in the direction of passive supervision. However, with the number of workers taking unsafe behaviors increases, contractors begin to strengthen supervision gradually with the intention of strengthening the punishment of workers and reducing the penalty from the government. If the cost to workers is lower, but is still higher than the utility improvement brought by safe behaviors, the system will be unstable (**Figure 4B**). If the cost of workers is lower than the utility improvement brought by safe behaviors, the improved effectiveness can offset the cost completely, therefore the system will evolve toward (0,1). With the number of workers with safe behaviors increasing, the evolution direction of contractors is to take active supervision reversely and finally the evolution direction of contractors will turn to passive supervision. Both parties will obtain a stable state at (0,1) in order to reduce the cost of supervision (**Figure 4A**).

SENSITIVITY ANALYSIS

The Impact of Initial Value

It is necessary to examine the impact of the initial state (x, y) on the final evolutionary stability. The evolution paths under two different scenarios are tested, as shown in **Tables 4**, **5**. In scenario 1, contractors have low supervision cost and construction workers have the medium safety cost. In scenario 2, contractors have the medium supervision cost but the workers' safety cost is the same with scenario 1. Both scenarios are common in engineering field. In scenario 1, the initial state point (0.1, 0.1), when few contractors tend to take active supervision and few workers take safe behaviors, is tested. The results are shown in the **Figure 5A**. The evolutionary trajectories increase gradually to ESS (1,1). The initial state (0.2, 0.6) and (0.7, 0.3) are tested as well. The results are shown in **Figures 5B,C**. From **Figures 5A–C**, we can find that: (1) when the value of parameters keep constant, the initial state (x, y) does not affect the final ESS; (2) the difference of the three figures is the time reaching ESS (1,1), which is influenced by the initial state.

In scenario 2, the evolution paths under the initial state points (0.1,0.1), (0.2,0.6), and (0.7,0.3) are also tested. The results are shown in **Figures 6A–C** respectively. By comparing these three figures, we can see that (1) the initial values of (x, y) will affect the final ESS under this parameter condition; (2) the time reaching ESS will be affected by the initial values of (x, y) as well.

Single-Factor Sensitivity Analysis

Finally, sensitivity analysis on individual factors is also conducted. The value of an individual factor is adjusted while other variables are kept consistent (as shown in **Table 6**) to observe the impact of this factor on the evolution, so

TABLE 4 | The parameter settings of scenario 1.

Item	F	C_1	C_2	R	G	α	β	p_1	p_2	L	Q_1	Q_2
Value	4.5	3.0	1.0	0.5	0.3	0.6	0.4	0.4	0.8	3.0	1.5	4.5

TABLE 5 | The parameter settings of scenario 2.

Item	F	C_1	C_2	R	G	α	β	p_1	p_2	L	Q_1	Q_2
Value	4.5	3.5	1.0	0.5	0.3	0.6	0.4	0.4	0.8	3.0	1.5	4.5

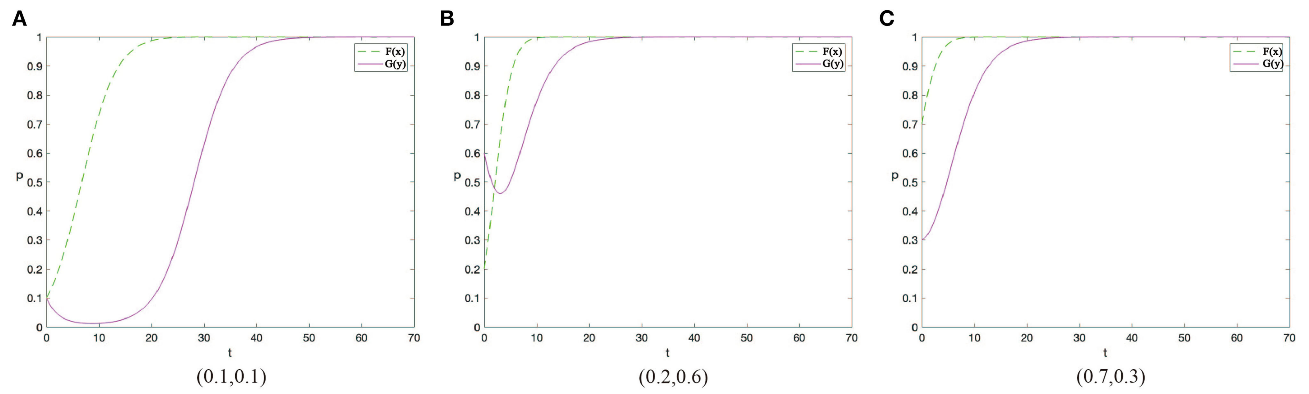

FIGURE 5 | The evolutionary trajectories of (0.1,0.1) **(A)**, (0.2,0.6) **(B)**, and (0.7,0.3) **(C)** in scenario 1.

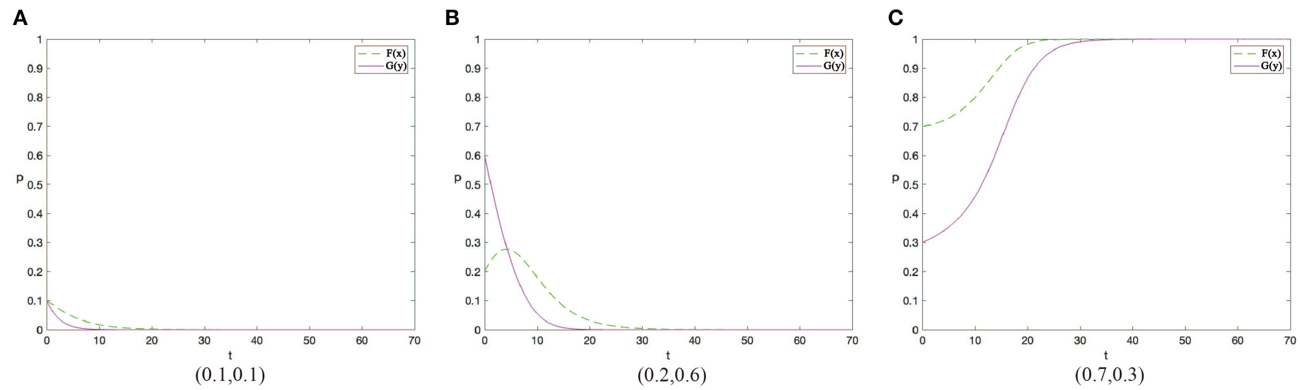

FIGURE 6 | The evolutionary trajectories of (0.1,0.1) **(A)**, (0.2,0.6) **(B)** and (0.7,0.3) **(C)** in scenario 2.

TABLE 6 | The parameter settings of single-factor sensitivity analysis.

Item	C_1	C_2	α	β	p_1	p_2	L	Q_1	Q_2
Value	3.0	1.4	0.6	0.4	0.4	0.8	3.0	1.5	4.5

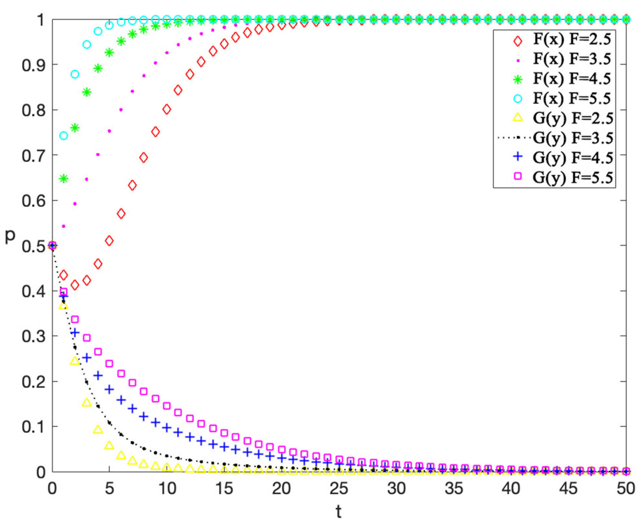

FIGURE 7 | The evolutionary trajectories influenced by F.

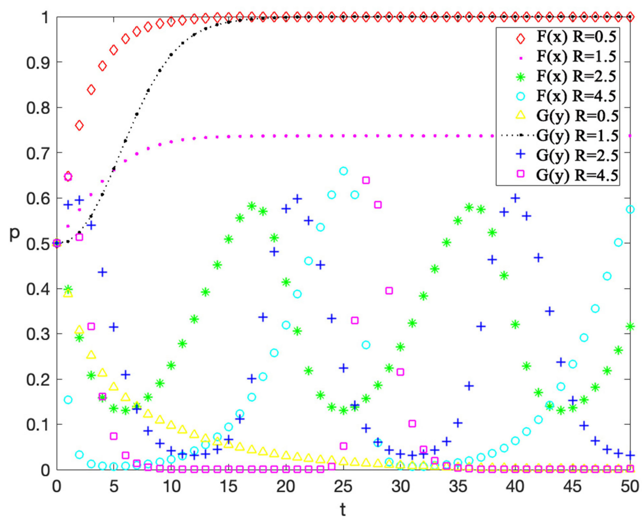

FIGURE 8 | The evolutionary trajectories influenced by R.

as to help managers to adjust behavior strategies more targeted. This analysis considers reputation incomes for contractors "*F*," rewards for workers' safe behaviors "*R*," and penalty costs for workers' unsafe behaviors on the evolution results "*G*" which have a great impact on behavior strategies of contractors and workers. The value setting of other variables represents a scenario when contractors have low supervision cost and construction workers have high safety cost which is a common phenomenon in practical situations.

The sensitivity analysis of "*F*" is shown in **Figure 7** and the values of "*R*" and "*G*" are 0.5 and 0.3 respectively. According to this figure, changing reputation incomes does not affect the final evolution result. However, it does influence the speed of evolution. With the increasing of reputational benefit, contractors are more likely to adopt active supervision, thus leading to a reduction in the probability of the workers' unsafe behaviors. This phenomenon suggests that the behavior of contractors and workers can be effectively guided and corrected by enhancing the contractor's perception of reputational income.

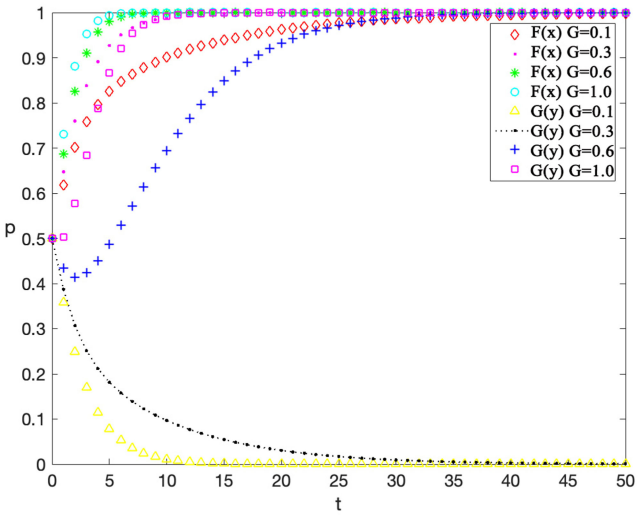

FIGURE 9 | The evolutionary trajectories influenced by G.

The sensitivity analysis of incentive *"R"* for worker's safe behavior is shown in **Figure 8** and the values of "*F*" and "*G*" are 4.5 and 0.3 respectively. It can be found that when contractors provide workers with more incentives, contractors take a lower active supervision and workers tend to take safe behaviors as the equilibrium point changes from (1,0) to (1,1). When *"R"* continues to increase, the strategies of both parties are then unstable. This phenomenon demonstrates that the incentive provided by contractors to workers should be established reasonably so that it can help increase the probability of workers to take safe behaviors as well as help contractors avoid the loss of taking excessive active supervision.

The sensitivity analysis of the contractors' penalty *"G"* for unsafe behaviors is shown in **Figure 9** and the values of "*F*" and "*R*" are 4.5 and 0.5 respectively. It can be found that as the penalty costs for unsafe behaviors increase, contractors are more likely to adopt an active supervision strategy, thus reducing the possibility of unsafe behaviors by workers. Finally, workers will take passive safe behaviors because they want to avoid unbearable penalties. Therefore, contractors will have sufficient profits to take active supervision. This phenomenon suggests that the probability of unsafe behavior of workers can be reduced by increasing the penalty.

CONCLUSION

In this paper, we construct a game model between contractors and workers, and then focus on comparing the evolution process of supervision behaviors from contractors and safe or unsafe behaviors from workers under different incentive and penalty mechanisms. The impact of the initial state and parameters on the behavior strategies of both parties is further investigated through simulation.

This has the following contributions to new knowledge related to establishing best strategies to improve safety performance of contractors and workers:

(1) The government and contractors should establish a reasonable incentive and penalty mechanism as a reasonable benefit allocation is crucial to enhance cooperation (Li et al., 2018). The analysis of evolutionary stability and sensitivity shows that the settings of incentive and punishment variables can impact the evolution direction and speed of strategies from contractors and workers. Other parameters (e.g., reputational benefit) are greatly affected by external factors, incentive and penalty mechanisms are completely dominated by contractors. Contractors and workers can adopt more positive strategies with appropriative incentive and penalty mechanisms.

(2) Mutual trust between contractors and workers should be strengthened as mutual trust can keep cooperative evolutionary direction and cooperative stability (Xue et al., 2010). The initial perceptions of both sides have a decisive impact on the evolution direction. Both parties are encouraged to strengthen communications with increased mutual trust as the results show that if the number of contractors and workers taking positive strategies increases at the beginning, a positive evolutionary stability can be obtained faster. In addition, more positive perceptions of both sides at the initial stage will lead to a positive evolution more quickly, which reduces the trial and error cost of both sides.

(3) Contractors are encouraged to raise the awareness of social responsibilities with reduced supervision costs, and improve the safety communication, education and publicity of construction workers. Strengthening safety governance has urgently become social responsibility that can't be shifted by contractors and government supervision departments (Zhang, 2009). The awareness of social responsibilities can be raised through a few strategies like the construction of the social credit system. Meanwhile, the supervision cost is likely to be reduced through the application of intelligent monitoring and warning technologies. Safety communication, education and publicity will help construction workers determine the suitable costs. These, if combined with an appropriate incentive and penalty mechanism, can help enhance the safety performance for both contractors and construction workers.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JZ contributed to conception, modeling, experiment, and writing. CZ contributed to the experiment and writing. SW contributed to the writing and checking. JY and QL contributed to review, editing, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

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ORIGINAL RESEARCH
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A Causation Analysis of Chinese Subway Construction Accidents Based on Fault Tree Analysis-Bayesian Network

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Clarifying the causes of subway construction accidents has an important impact on reducing the probability of accidents and protecting workers' lives and public property to a greater extent. A total of 138 investigation records of subway construction accidents from 2000 to 2020 were collected in this study. Based on a systemic analysis of 29 well-known accident causation models and the formative process of the subway construction accidents, we extracted the causative factors of subway construction accidents from the collected records. Furthermore, a causation analysis index system of subway accidents was proposed based on fault tree analysis (FTA), where we considered subway construction accidents as the top event and the five dimensions, i.e., human, equipment, environment, management, and safety culture, as first-level intermediate events. Moreover, 17 causative factors were considered to be related to the severity of subway construction accidents. It is found that human factors are prone to be critical to high-risk accidents. Finally, a Bayesian network (BN) was formed to explore the causative factors of high-risk subway construction accidents. Based on the combined application of FTA and BN, this study discusses the complex influence factors and their action routes to unsafe accidents in subway construction sites, and makes efforts to correspond safety decision basis for the management of China subway construction.

Keywords: Chinese subway construction, construction safety, cause factors, fault tree analysis, Bayesian-network

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INTRODUCTION

The subway, as a symbol of modern metropolis development, plays a critical role in reducing traffic congestion, improving urban structure, and developing regional economies. Since the implementation of the New Infrastructure Construction policy in 2020, China has accelerated the development of the rail transit industry, and subway construction plans have gradually expanded from large-sized cities to medium-sized cities. As of 31 December 2021, subways have been in operation in 40 cities in mainland China, covering a total distance of 7,253.73 km (China Association of Metros, 2022). Meanwhile, subway constructions are prone to safety accidents for their complex construction environment, strict technical requirements, and high safety risks. The threat to workers' lives and public property cannot be ignored. Therefore, strengthening the management and control of causative factors for subway construction accidents has become an urgent research topic.

The desire for safety drives people to learn from past accidents and experiences. The investigation reports and related records of subway construction accidents are valuable and precious in identifying the causes of subway construction accidents and improving the management capacity of accident prevention. Therefore, this study tried to collect the subway construction accident cases in China on record from 2000 to 2020 as the sample data. Combined the practice cases with classic accident-causing models, a causation mechanism tree of subway construction accidents was constructed by using the fault tree analysis method (FTA), which is helpful to comprehensively identify the causative factors of subway construction accidents in China. Furthermore, a Bayesian network (BN) was applied to dynamic causation analysis and risk inference for high-risk subway construction accidents. We hope this study will be conducive to reducing the risks in subway construction projects and providing decision support for the safety management of infrastructure construction in China.

The remainder of this study is organized as follows: First, we discussed the literature review. Then, we described the data acquisition and analysis framework, and developed a causation analysis index system of subway construction accidents based on FTA. Furthermore, we analyzed the causation of high-risk subway construction accidents, where a BN model is presented. Finally, the conclusion and further study are presented.

LITERATURE REVIEW

Understanding the accident-causing mechanism has always been considered as a prerequisite to prevent accidents, and it will benefit the improvement of construction management and technology. Therefore, a number of accident causation models have been developed in view of different fields.

Accident causation models, which are important theoretical bases and research methods in safety science, reflect a systematic analysis of the occurrence, development, and consequence of an accident (Fu et al., 2019). **Figure 1** shows some emerging classic accident causation models over the past 100 years, which can be divided into four categories, namely, human error models, simple linear models, complex linear causation models, and systemic models (Katsakiori et al., 2009; Khanzode et al., 2012; Fan et al., 2014; Fu et al., 2019; Woolley et al., 2019; Wu et al., 2020). These accident causation models examine the causes of accidents from the initial worker factors, equipment factors to gradually breaking through the restrictions of the workplace, spreading to distant factors such as organization, safety atmosphere, and social environments (Khosravi et al., 2014).

In addition, the accident causation models have become more networked and multidimensional, showing the evolution process like "point-line-surface-space" (Huang and Wu, 2017). For existing accident causation models, they are proposed at certain historical periods, under specific circumstances and assumptions, hence different models come with various research emphases (Huang L. et al., 2020). However, among these models, the discussion on human errors (e.g., worker factors and management factors) is never absent. It means that human-related factors are always considered to be fundamental to accidents. For example, Hung et al. (2011) adopted a triangulation design consisting of observation, subjective quantitative, and subjective qualitative methods, concluding that safety problems and dangerous behaviors are affected by construction workers' safety attitudes. Williams et al. (2018) studied accident causation classification and categorized it under five factors, namely, client-related, consultant-related, contractor-related, construction workers-related, and construction site-related. Clarke (2013) explored the impact of different styles of leadership on safety using meta-analytic path analysis.

The uncertainty associated with the underground construction environment (Seo and Choi, 2008) makes subway construction far more complex and generates much more serious accident consequences than general construction projects (Xing et al., 2019). Moreover, subway, as a critical infrastructure essential to social and economic development, has specific characteristics in its construction process compared to general construction projects, as well as in multiple stakeholders such as government, enterprises, and citizens. At present, accident studies in the field of public infrastructure construction like subway mainly focus on technical, geological, and environmental safety risk factors (Ding et al., 2012). Since accidents in complex environments are resulted from multiple causes combined (Chen et al., 2020), a comprehensive review of subway construction accident risk factors is warranted. Some studies explored the multiparty or multilevel causative factors in a major subway construction accident with a certain accident causation model. For instance, Niu et al. (2016) established a structural model of subway construction safety control based on the STAMP model, which is used to investigate the causal factors of the 2008 Hangzhou subway collapse. Besides, another group of studies investigated the causative factors through a large number of subway construction accident cases. Typically, Zhou et al. (2021) developed a network of SCSRN to integrate causations with various accidents on subway construction sites. He (2018) coded 57 subway construction accidents in China based on grounded theory, and extracted accident causal factors into four core genera, i.e., management, human, environmental condition, and physical factors.

In conclusion, there are already several classic accident causation models which can help a lot when clarifying the causes of subway construction accidents. At the same time, due to the specific characteristics of subway construction projects, it is worth noting that the adaptability and pertinence of these models for subway construction accident analysis should be further optimized. The study of influencing factors based on only subway accident data often leads to ignoring the gradual development process of accidents. Therefore, we intended to explore an integrated way, in which accident causation models can be adjusted by combining with actual details of the subway construction accidents, and the static analysis of the causative factors, as well as dynamic prediction, can be accomplished. For this purpose, we introduced a hybrid approach with FTA and

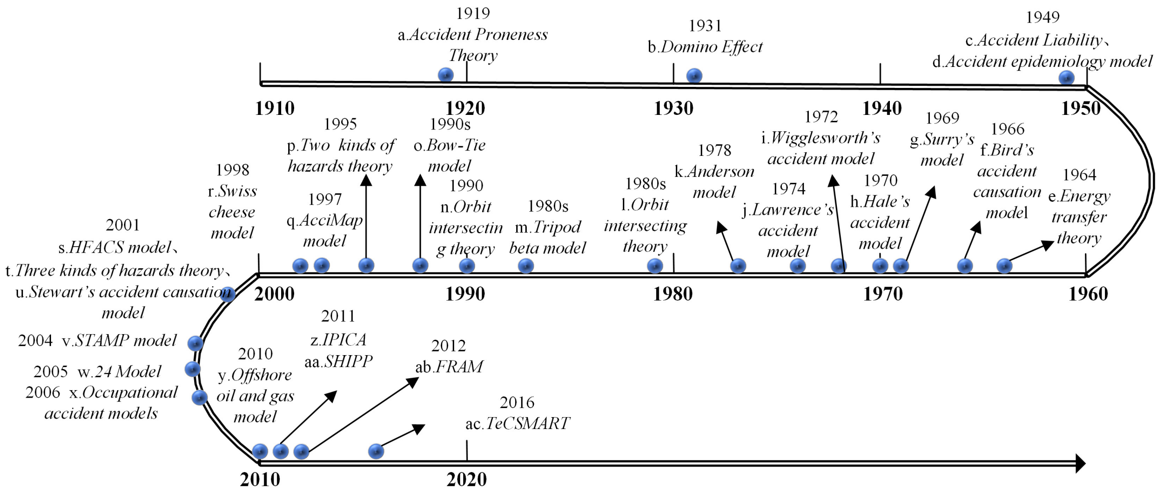

FIGURE 1 | Accident causation model diagram.

TABLE 1 | Statistics of accident cases.

Accident code	Subway line	Time	Accident consequences	Accident level	Detailed description of the cases (data source)
1	Shanghai	2001-8-20	Four people killed	Lager accident	http://www.riskmw.com/case/2010/07-23/mw22487.html
2	Line 1, Hangzhou	2008-11-15	Twenty one people were killed; 24 people injured; direct economic loss reached 49.61 million Yuan	Major accident	http://www.hangzhou.gov.cn/art/2017/7/9/art_1256343_8272707.html
3	Line 4, Suzhou	2016-8-4	One person killed; direct economic losses amounted to about 1.05 million Yuan	Ordinary accident	http://yjglj.suzhou.gov.cn/szsafety/sgdccl/201612/2b34b904f2ff48cc8110f93e5aaff377.shtml
...	...	...	...	...	...
138	Line 4, Shenzhen	2020-7-29	One person killed; direct economic loss reached 1.8 million Yuan	Ordinary accident	http://www.szlhq.gov.cn/zdlyxxgk/aqsc/dcbg/content/post_8176254.html

Accident levels are classified according to the Regulations on the Reporting and Investigation of Workplace Accidents in China.

BN. The literature review on accident causation models provides theoretical support for establishing the causation index system of subway construction accidents.

METHODOLOGY

After a major accident, most countries will provide accident investigation reports to the public. Although the standards of accident report preparation differ from country to country, the report's core components are generally similar. A typical accident investigation report not only provides a summary and recommendations on the consequences of the accident, but also documents the details of the safety event and the determining factors that may cause the accident. We planned to use the information extracted from the accident investigation report for data analysis. Therefore, the data collection and processing of subway construction incidents are discussed in the following sections.

Data Acquisition

The scope of the data was the subway construction accidents occurred between 2001 and 2020. The provinces (autonomous regions and province-level municipalities) for the accident collection were only within mainland China, excluding Hong Kong, Macau, and Taiwan Province. The data were mainly collected from Emergency Management Bureau websites, Housing and Urban and Rural Construction Bureau websites at various levels, official media, security forums, etc. Finally, 138 investigation reports of subway construction accidents with relatively comprehensive information were acquired. There were eight non-production safety liability accidents. For the remaining 130 subway construction accident records, there were 109 low-risk accidents (ordinary accidents) and 21 high-risk accidents. The statistical items of cases collected are shown in **Table 1**.

Analysis Framework

Fault tree analysis is a graphical interpretation method that can capture the causes of system failures or the probability of accidents. It uses logical symbols to link system failures and the factors that cause them and operate based on Boolean logic, which is considered to be an effective way of system security assessment (Lawrence and Gill, 2007). The fault tree analysis method was developed by the telephone laboratory of

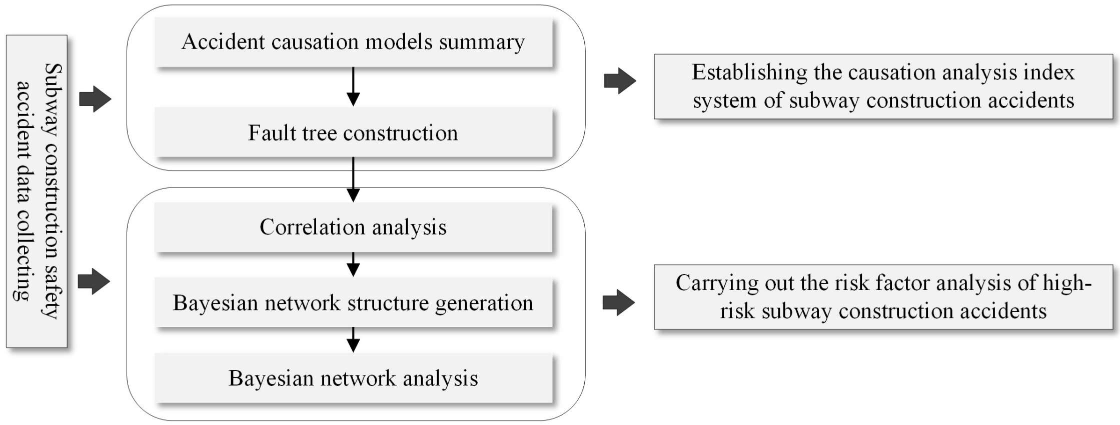

FIGURE 2 | Framework for data analysis.

Bell Telegraph Company in 1962 and was originally applied in the fields of aerospace, military, nuclear energy, and navigation. Subsequently, as the method became more influential, it was introduced into cross-disciplinary areas (Wang et al., 2019; Liu et al., 2021).

Fault tree analysis takes the most undesired event of the system as the target of fault analysis and looks for all factors that directly cause this occurring fault event. The analysis goes down in sequence until those factors are found for which the probability distribution is known and no further exploration is required. A complete fault tree analysis method generally includes the following steps: establishment of fault trees, normalization of fault trees, qualitative analysis, quantitative analysis, etc. Researchers can operate several or all of these steps according to the study demands. "The causation analysis index system of subway construction accidents based on fault tree analysis" section uses the fault tree method, establishing a subway construction accident causation analysis index system.

The BN, also known as the Bayesian belief network, is composed of network nodes, directed edges, and conditional probability table (CPT), which is the product of the combination of probability theory and graph theory. It uses directed acyclic graphs (DAG) to qualitatively describe the dependencies among nodes and the conditional probability distribution or CPT of each node to quantitatively express the influence relationships among nodes, providing reliability in the problems with uncertainty and incompleteness through limited samples or missing data (Xie, 2015). The Bayesian network is based on the Bayesian inference formula. For the event "L", assuming that the sum of all events affecting its occurrence is $X = (X_1, X_2, X_3, \ldots X_n)$, the Bayesian formula can be calculated as follows:

$$P(X_i \mid L) = \frac{P(L \mid X_i)P(X_i)}{P(L)} = \frac{P(L \mid X_i)P(X_i)}{\sum_{j=1}^{n}(L \mid X_j)P(X_j)},$$

$$i = 1, 2, 3, \ldots, n, n \in N^{+} \quad (1)$$

where X_i is the causative factor in the set $X.P(X_i)$ is the prior distribution, generally obtained from expert experience or historical data statistics. $P(L \mid X_i)$ is the likehood function. $P(L)$ is the probability of the occurrence of event L, which can be calculated by the full probability formula. $P(X_i \mid L)$ is the posterior distribution.

The above ones are the main technical methods to solve the problems in "The causation analysis index system of subway construction accidents based on fault tree analysis" and "Causation analysis of high-risk subway construction accidents based on Bayesian networks" sections, and our analysis process is shown in **Figure 2**. First, we collected the case data of subway construction accidents during recent 20 years. Then we developed a causation analysis index system of subway construction accidents based on fault tree analysis. In this process, we extracted the primary indicators from the classical accident causal models, which provide the theoretical support for the fault tree construction. Furthermore, correlation analysis was used to select the causative factors associated with high-risk subway construction accidents. Finally, a BN is established for the dynamic causation analysis and risk inference of high-risk subway construction accidents.

TABLE 2 | The first-level intermediate events of fault tree analysis (FTA).

Accident causation model	Causation dimension
a; b; c; f; g; h; i; j; l; n; q; r; s; u; v; w; x; and *aa*	Worker factors
b; f; h; l; u; w; and *ac*	Equipment factors
b; c; f; l; m; q; r; s; x; z; and *ac*	Environmental factors
e; f; h; j; l; n; q; r; s; u; v; w; x; z; aa; and *ac*	Organizational management factors
s; u; w; and *x*	Safety culture factors

The numbers "a-ac" in this table correspond to the numbers "a-ac" in ***Figure 1****.*

The Causation Analysis Index System of Subway Construction Accidents Based on Fault Tree Analysis

According to the principle of fault tree construction, the "occurrence of subway construction accident" is regarded as the top event (T) of the fault tree which should be subdivided into basic risk-causing factors. We first summarized some classical accident causation models (shown in **Figure 1**). Based on these classic models, the causes of subway construction accidents were refined into five dimensions, namely, worker factors, equipment factors, environmental factors, organizational management factors, and safety culture factors (see **Table 2**), which constitute the first layer of intermediate events of the fault tree. Furthermore, the following subsections introduce the classification standards of secondary and tertiary indicators. Based on the historical subway construction accident reports, the primary indicators were progressively classified into 33 basic factors, so as to establish the causation analysis index system of subway construction accidents in China.

Worker Factors

Worker factors refer to the direct operators, which are classified into unsafe characteristics and unsafe behaviors concerning the Human Factors Analysis Classification System (HFACS). The unsafe characteristics of workers include the poor psychological state and poor physical state. As for workers' unsafe behaviors, we referred to the studies of Reason (1990); Man (2013), and Ma et al. (2014) to divide them into two categories, namely, unintentional and intentional. Unintentional unsafe behavior refers to an incorrect or improper response to external stimuli due to the actor's perception bias, judgment error, and information transmission error, i.e., the actor's next operation is often a natural instinctive reaction (Jiang, 2021), for example, working under a crane weight without realizing a crane weight in front of them, not knowing the safety hazards, or not wearing a helmet due to insufficient safety knowledge. Intentional unsafe behaviors refer to the behaviors with a clear purpose such as saving time and effort, or knowingly violating the rules (Chen et al., 2007). For example, during the construction process, though workers know that some behaviors do not meet the safety standards, they still take those fluke behaviors, including going to work after drinking, working when fatigued, and violating regulations after receiving complete safety education and training.

Equipment Factors

It can be observed from the accident cases that the equipment factors mainly refer to the failure of machinery equipment, consisting of the following two situations: the equipment running with disease due to negligence of daily inspection and maintenance, and the sudden failure of equipment due to equipment design defects or improper use and other reasons.

Environmental Factors

Subway construction is mostly carried out in underground spaces, which are narrow and easily affected by the surrounding geological environment, pipeline factors, ground traffic disturbance, and weather. The environmental factors that affect subway construction accidents can be divided into two categories, namely, organizational internal environmental factors and organizational external environmental factors. Among them, organizational internal environmental factors mainly refer to the problems in the operating environment of the workplace, such as cross-operation on the construction site, irregular placement of materials and equipment, low lighting, lack of monitoring equipment, and other safety hazards. Furthermore, the external environmental factors of the organization are divided into natural environmental factors, technical environmental factors, and policy environmental factors. Among them, natural environment factors mainly involve unfavorable geological and hydrological environments as well as meteorological factors. Surface subsidence and building damage accidents caused by poor geological and hydrological environments frequently occur in the process of subway construction in China. In addition, extreme weather, such as heavy rain, increases not only the difficulty of construction but also the probability of accidents by worsening the geological and hydrological conditions. Technical environmental factors mean the environmental conditions that are unfavorable for construction caused by human activities, which mainly refer to the ground vibration caused by human activities and the complex, unexplored or old underground pipelines that affect the construction. Policy environment factors refer to the subway accident occurred when related technology, standards, and norms have not been issued, thus making the subway construction in an environment without evidence.

Organizational Management Factors

Organizational management factors can directly or indirectly cause the system in a failure state, thereby increasing the probability of accidents (Xiao and Li, 2007). Therefore, it has become the consensus of most accident models to regard organizational management factors as the deep-seated causes of accidents. In essence, organizational management factors belong to human factors. Although they are partially identical, the mechanisms of organizational management errors are much more complex than those of individual mistakes. For the classification of organizational management factors, this study classifies them concerning the Plan Do Check Act (PDCA) method (Li and Huang, 2018), which divides management activities into four stages: Plan, Do, Check, and Act, and regards management activities as a continuous process that runs continuously in a cycle. Since the data collected in this study contain no factors related to "Act," we divided the organizational and management factors of subway construction accidents into three categories, namely, Plan, Do, and Check, according to the research purpose.

When defining the Plan factors for subway construction accidents, we interpreted them as insufficient construction objectives, plans, methods, and specific measures formulated. Specifically, it is divided into three sub-dimensions, namely, insufficient foreseeability of safety accidents, planning and design deficiencies, and construction plan deficiencies. Among them, inadequate foreseeability of safety accidents refers to the situation where the subway construction unit misjudges the overall risk of construction due to weak safety awareness or a lack of relevant knowledge. Deficiencies in planning and design include defects in construction scheme design, confusion in the management of construction plans, and so on. The construction plan deficiency mainly includes the following three situations, i.e., the complete lack of the construction flow scheme, the partial lack of the construction scheme, and the complete construction scheme which is equal to the lack because of the vague expression.

The Do phase of the PDCA cycle is the stage of strict implementation of the formulated objectives and plans, and the implementation factors leading to the occurrence of subway construction safety accidents can be summarized into six sub-dimensions, namely, insufficient emergency response capabilities, deviation of construction plan execution, inadequate communication procedures, contract management deviation, subcontract management loopholes, and resource management disorder. Insufficient emergency response capabilities in subway construction accidents are mainly manifested by the absence of emergency plans and improper emergency handling at construction sites. Deviation of construction plan execution refers to the deviation or violation of construction plan in the process of subway construction, including the violation of technical regulations, violation of construction procedures, inadequate safety hazard inspection, and inappropriate implementation of technical delivery. Inadequate communication procedures mainly refer to the communication problems existing in the subordinate and subordinate departments and the departments at the same level in the process of subway construction. Contract management deviation refers to the situation that there are obvious errors in the process of contract formulation procedures and contents as well as obvious deviations in contract implementation during the subway construction process. Subcontracting management loopholes mainly refer to illegal subcontracting and escrow by subcontracting in the process of subcontracting. Resource management disorder includes two situations, i.e., human resource management disorder and material management disorder.

The Check factors leading to subway construction accidents mainly include three sub-dimensions, namely, inadequate construction monitoring, inadequate project supervision, and inadequate government supervision. Among them, inadequate construction monitoring refers to the following situations: inadequate supervision and management of the construction site by the construction unit, inadequate ivariables are treatnternal supervision and inspection of the project, and inadequate monitoring of the construction site. Moreover, inadequate project supervision refers to problems such as unqualified supervisors, absence of supervisors during inspections, and ineffective performance of supervisors in the process of third-party supervision. Inadequate government supervision mainly refers to the existence of poor communication and coordination between enterprises and government departments, imperfect relevant government rules and regulations, problems with enterprises in permitting construction procedures, the ineffective performance of relevant government departments, lax inspections, etc.

Safety Culture Factors

"Safety culture" is the guiding ideology of safety operations at the organizational level (Fu et al., 2013), a term that has rapidly gained acceptance and has become popular among safety researchers worldwide since it was first used in the report of the International Nuclear Safety Advisory Group (INSAG) in 1986 (David and Zhang, 2021). Over the years, different scholars have formed different opinions on the connotation of safety culture. As safety culture is a subset of organizational culture; this study draws on Schein's three-level model of organizational culture, i.e., organizational culture includes shallow worker artifacts, implicit values, and the deepest basic assumptions (Yan et al., 2015). We considered that the safety culture factors leading to subway construction accidents can be divided into three categories, namely, implementation level, management level, and system level. Specifically, according to the accident cases, they are summarized as non-execution of safety education and training, inadequate safety management systems, management's lack of attention to safety production, and failure to implement safety regulations and systems. Among them, non-execution of safety education and training and the failure to implement safety regulations and systems refer to safety culture factors at the implementation level. Non-execution of safety education and training mainly means that safety training for workers is not carried out or perfunctory. Failure to implement safety regulations and systems refers to the failure of management personnel to implement relevant laws, norms, or regulations. Management's lack of attention to safety production is a factor at the management level, including the risky construction ordered by managers in pursuit of economic benefits, the long-term absence of site duties, "Three Violations" activities, and so on. The inadequate safety management system is a factor at the system level, which mainly includes the insufficient rules and regulations and unclear management structure of the enterprise. **Figure 3** shows the "subway construction accident causation mechanism tree," which demonstrates the causative factor index system of subway construction accidents in China, and **Table 3** provides a detailed supplement to **Figure 3**.

CAUSATION ANALYSIS OF HIGH-RISK SUBWAY CONSTRUCTION ACCIDENTS BASED ON BAYESIAN NETWORKS

According to the Regulations on the Reporting and Investigation of Workplace Accidents (The Central People's Government of the People's Republic of China, 2007), accidents that result in less than three deaths, fewer than 10 serious injuries, or less than 10 million Yuan in direct economic losses are defined as ordinary accidents. They account for the largest proportion of workplace accidents, and we defined them as low-risk accidents. As mentioned above, the accident consequences are generally measured by casualties and property losses. When the number of fatalities reaches three or more, it means that the accident reaches the level of a major accident. It is prone to significant negative social impacts. Although such accidents occur infrequently, they will cause great physical losses and hidden damage to the reputation of the project team and local government. Accidents of this level are defined as high-risk accidents in this study, e.g., the Qingdao subway collapse on 27 May 2019, which formed a superimposed effect of public opinion with the self-report of subcontractor, and caused strong concerns and doubts from public opinion about the project

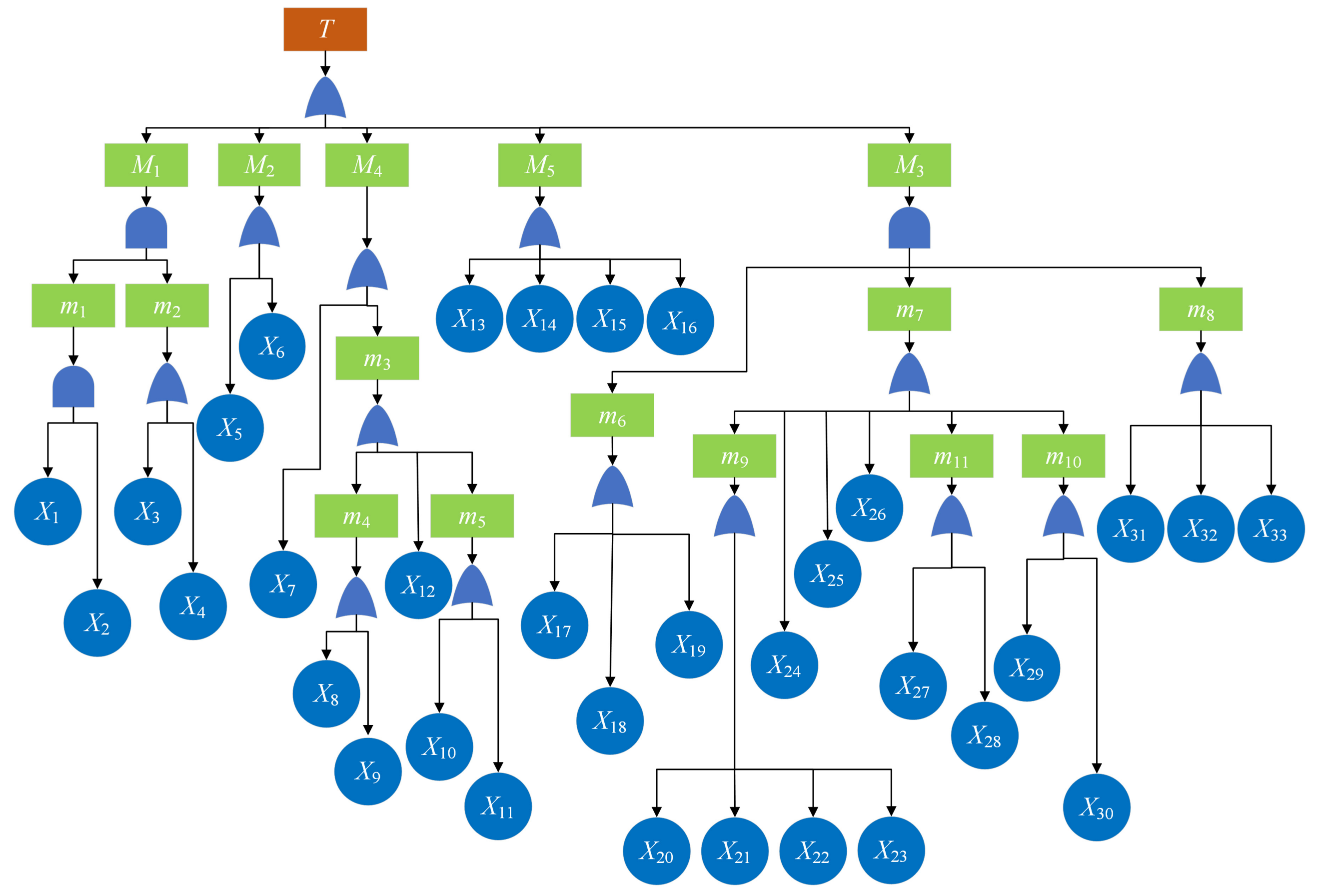

FIGURE 3 | Subway construction accident causation mechanism tree.

parties and Qingdao municipal government (Zhang and Shao, 2019). Therefore, much attention should be given to the high-risk subway construction accidents, particularly the management and control of related risk factors associated with subway construction accidents at this level.

In this section, the risk factors related to the severity of subway construction accidents are extracted from the subway construction accident causation index system through correlation analysis. Then the dataset is matrixed and a Bayesian network is constructed to analyze the causes of high-risk subway construction accidents. The Bayesian network is obtained in GeNIe3.0, including structure learning, parameter learning, model accuracy verification, and empirical analysis. The BN build process is shown in **Figure 4**.

Correlation Analysis of the Causative Factors of High-Risk Subway Construction Accidents

As many as 33 basic causative factors of subway construction accidents were identified using fault tree analysis, which makes it difficult to guarantee the accuracy of BN constructed using these factors. To simplify the model structure and improve the efficiency of the BN structure learning, before learning the Bayesian network structure, we first conducted a correlation analysis between each causal variable and the variable "Severity of Subway Construction Accidents" (Li et al., 2014; Zhang and Sheng, 2019), so as to delete variables that are not strongly correlated with the study variable. For the correlation analysis, the severity of subway construction accidents was used as the dependent variable, while the other 33 causative factors were used as the independent variables. These variables are treated as dummy variables in SPSS. Herein, the occurrence of high-risk subway construction accidents is defined as "1", and the low-risk subway construction accidents are defined as "0"; for the 33 risk factor variables, the two-state values of "occurred" and "not occurred" are presented with "1" and "0", respectively. SPSS.26 was used to carry out the correlation analysis between each variable and low-risk subway construction accidents. As shown in **Table 4**, there are 17 causative factors related to the severity of subway construction accidents.

Establishment of the Causative Factor Matrix

Before constructing the Bayesian network model of high-risk subway construction accidents, we need to preprocess the data

TABLE 3 | Subway construction accident causation index explanation.

Index number	Causative factor	Index number	Causative factor
M_1	Worker factors	X_{10}	Unfavorable geological and hydrological environments
M_2	Equipment factors	X_{11}	Meteorological factors
M_3	Organizational management factors	X_{12}	Policy environmental factor
M_4	Environmental factors	X_{13}	Management's lack of attention to safety production
M_5	Safety culture factors	X_{14}	Inadequate safety management system
m_1	Workers' unsafe characteristics	X_{15}	Failure to implement safety regulations and systems
m_2	Workers' unsafe behavior	X_{16}	Non-execution of safety education and training
m_3	Organizational external environmental factors	X_{17}	Insufficient foreseeability of safety accidents
m_4	Technical environmental factors	X_{18}	Planning and design deficiencies
m_5	Natural environmental factors	X_{19}	Construction plan deficiencies
m_6	Plan factors	X_{20}	Violation of technical regulations
m_7	Do factors	X_{21}	Violation of construction procedures
m_8	Check factors	X_{22}	Inadequate safety hazard inspection
m_9	Deviation of construction plan execution	X_{23}	Inappropriate implementation of technical delivery
m_{10}	Insufficient emergency response capabilities	x_{24}	Inadequate communication procedures
m_{11}	Resource management disorder	X_{25}	Contract management deviation
X_1	Workers' poor psychological state	X_{26}	Subcontract management loopholes
X_2	Workers' poor physical state	X_{27}	Human resource management disorder
X_3	Intentional unsafe behavior	X_{28}	Material management disorder
X_4	Unintentional unsafe behavior	X_{29}	Absence of emergency plans
X_5	Equipment running with disease	X_{30}	Improper emergency handling at construction sites
X_6	Sudden failure of equipment	X_{31}	Inadequate construction monitoring
X_7	Organizational internal environmental factors(problems in the operating environment of the workplace)	X_{32}	Inadequate project supervision
X_8	Ground vibration caused by human activities	X_{33}	Inadequate government supervision
X_9	Underground pipeline factors		

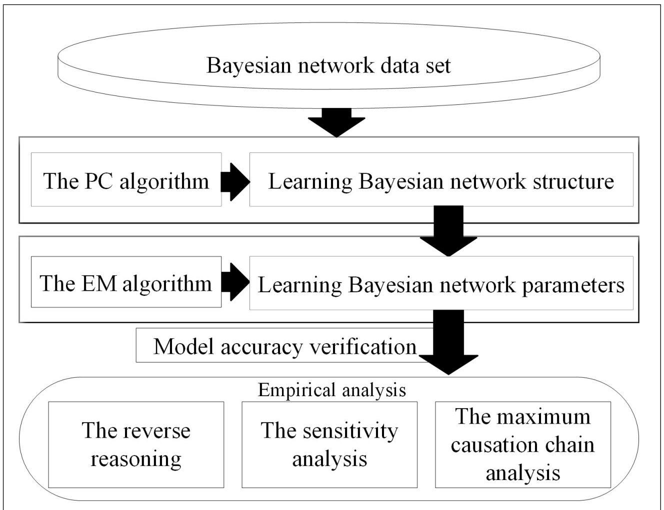

FIGURE 4 | The Bayesian network build process.

obtained combining with the results of correlation analysis. As shown in Eq. (2), $x_i$indicates the causative factor i, where $i \in \{1, 2, 3, \ldots, n\}$, n is the total number of causative factors related to the severity of subway construction accidents, and $n \in N^+$; c_k represents the accident case k, where$k \in \{1, 2, 3, \ldots, m\}$, m is the number construction accidents, and $m \in N^+$. Then we can build the causative factor matrix U_{mn} as follows:

$$U_{mn} = \begin{bmatrix} U_{c1x1} & \cdots & U_{c1xn} \\ \vdots & \ddots & \vdots \\ U_{cmx1} & \cdots & U_{cmxn} \end{bmatrix} \quad (2)$$

$$Where\ U_{ckxi} = \begin{cases} yes, & x_i \text{ occurs in accident } c_k \\ no, & x_i \text{ did not occur in accident } c_k \end{cases},$$

$$\forall x_i,\ i \in 1, 2, 3, \ldots, n,\ n \in N^+,$$

$$\forall c_k,\ k \in 1, 2, 3, \ldots, m,\ m \in N^+ \quad (3)$$

Bayesian Network Empirical Analysis

The establishment of the BN structure plays an important role in the validity of the model, which is the critical part of Bayesian network analysis. At present, there are generally three ways to establish a Bayesian network structure: learning algorithms based on sample data, expert knowledge in the case of missing data or clear causality, or using the two methods together.

Concerning the three methods mentioned, obtaining the Bayesian network structure through a dataset-based learning

TABLE 4 | Correlation analysis.

Causal variable	Correlation	Causal variable	Correlation	Causal variable	Correlation
X_1	−0.039	X_{12}	0.350**	X_{23}	−0.052
X_2	0.072	X_{13}	0.249**	X_{24}	0.017
X_3	−0.148	X_{14}	0.157	X_{25}	0.322*
X_4	−0.132	X_{15}	−0.012	X_{26}	0.063
X_5	0.217*	X_{16}	0.083	X_{27}	0.346**
X_6	−0.048	X_{17}	0.375**	X_{28}	0.154
X_7	0.024	X_{18}	0.180*	X_{29}	0.365**
X_8	0.238*	X_{19}	0.004	X_{30}	0.450**
X_9	−0.037	X_{20}	0.322**	X_{31}	0.217*
X_{10}	0.334**	X_{21}	0.205*	X_{32}	0.393**
X_{11}	0.322**	X_{22}	0.093	X_{33}	0.299**

*$p < 0.05$; **$p < 0.01$.*

algorithm can reduce the influence of the researchers' subjective factors to a large extent. However, with a limited data access, the effect of the structure learned only by data is not perfect, so it is necessary to add expert knowledge to adjust and revise the model. The PC algorithm is a classic learning algorithm based on sample data, which can separate the conditional independence relationship from the network structure search, and is closer to Bayesian semantic features in principle (Li, 2014). Therefore, this study chose PC algorithm to learn the BN structure, and adjusted the model through correlation analysis. Finally, the BN is obtained as shown in **Figure 5**, where "*L*" represents the severity of the subway construction accident.

We can learn the parameters of each variable based on the acquired sample data to obtain the CPT of each network node in the model. As the parameters of BN, CPT can quantitatively analyze the correlation between nodes. In general, Bayesian parameter learning methods include EM algorithm, maximum likelihood method, Bayesian estimation method, etc. (Zhang et al., 2012). Our data were collected from real accident investigation reports, in which there may exist incomplete records and a limited sample size of the reports. In this case, the EM algorithm can make up for the insufficiency of the report and accurately reflect the probability value between nodes. Meanwhile, the convergence speed of EM is faster (Huang W. C. et al., 2020). Hence, we chose the EM algorithm for parameter learning and obtain the Bayesian network parameter learning results (**Figure 6**).

The prediction accuracy of the model was calculated by "K-fold cross-validation" of the GeNie software, whose prediction accuracy is 0.8846150. It means that our model has high prediction accuracy and can be used for causation analysis and model inference.

The Reverse Reasoning

Reverse reasoning is the most common conditional probability reasoning method for Bayesian network models, that is, by pre-setting the risk level of the severity of subway construction accidents, the probability of each causative factor under this level is reasoned, so as to diagnose the most likely cause of the risk level accident. After reverse reasoning, we can calculate the posterior probability of each factor, and then determine the importance of the causative factors to the target node. Factors with a large posterior probability have a greater impact on the resulting events and are the goals we should focus on controlling and improving. The posterior probability of each causative factor is shown in **Figure 7**, and its comparison with the change of the prior probability is shown in **Figure 8**. As

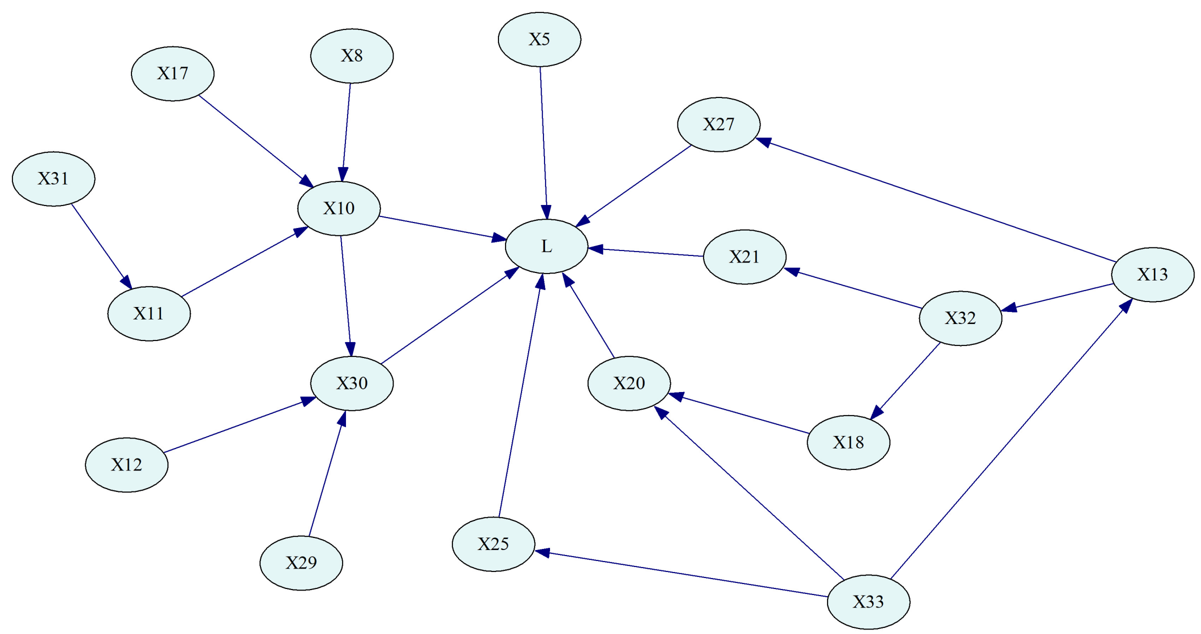

FIGURE 5 | Bayesian network structure learning results.

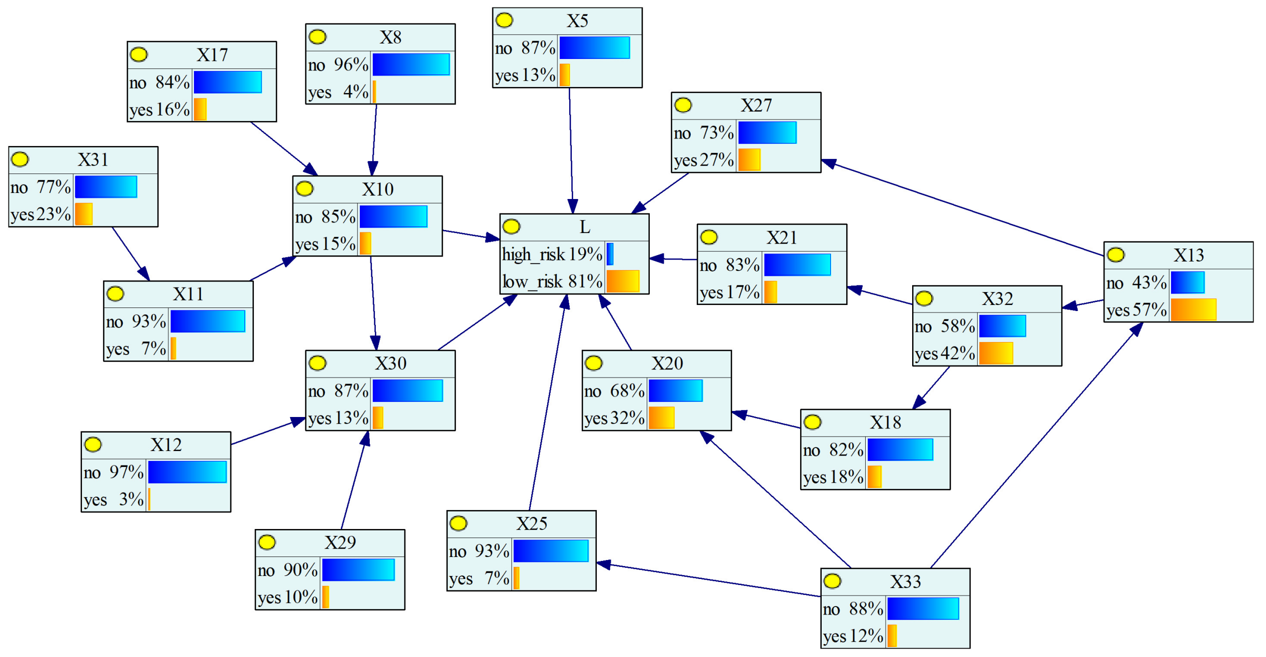

FIGURE 6 | Bayesian network parameter learning results.

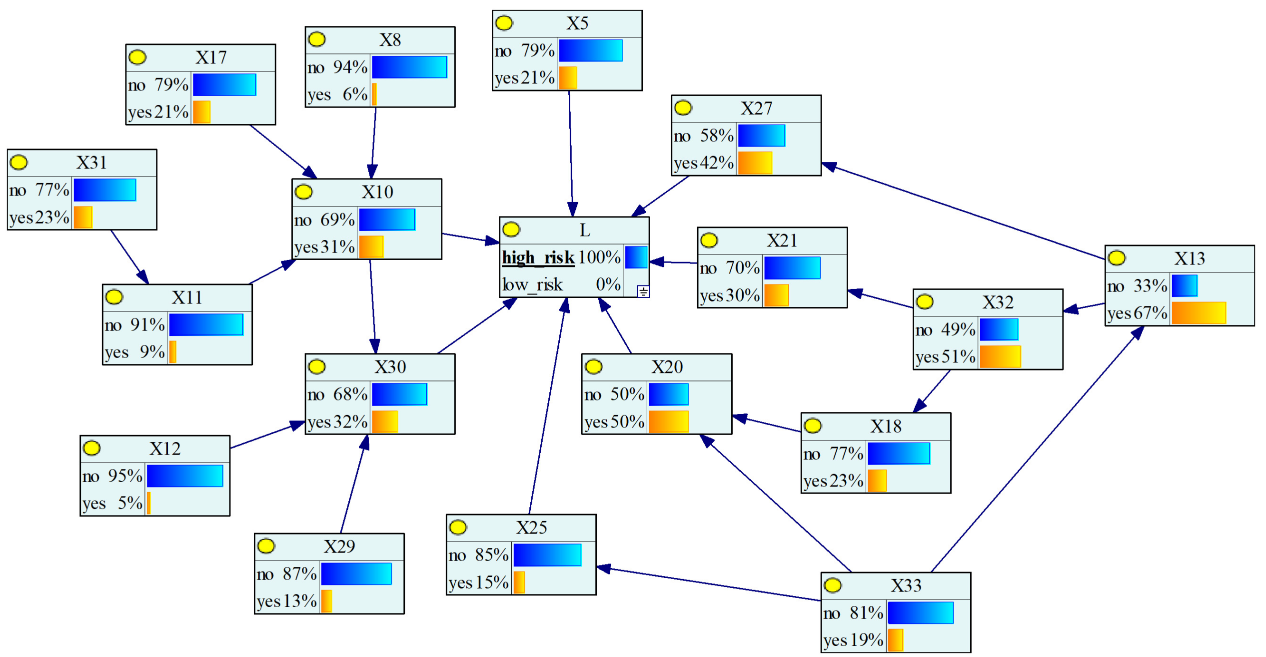

FIGURE 7 | Bayesian network reverse reasoning results.

can be seen from the figure, the posterior probability of the four causative factors X_{13}, X_{32}, X_{20}, and X_{27} is higher when a high-risk subway construction accident occurs. In other words, when high-risk subway construction accidents occur, the four risk-causing factors, i.e., management's lack of attention to safety production, inadequate project supervision, violation of technical regulations, human resource management disorder are more likely to occur. Among them, the consistent causative factor "X_{13}" has the highest prior probability and posterior probability, and is the most likely key risk factor for accidents. This situation shows a series of behaviors such as project leaders not being at the construction site, ordering "Three Violations" (i.e., surveying,

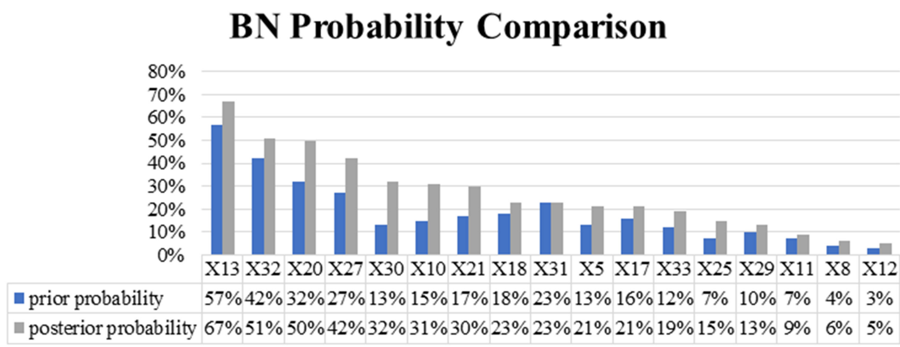

FIGURE 8 | Bayesian network probability comparison.

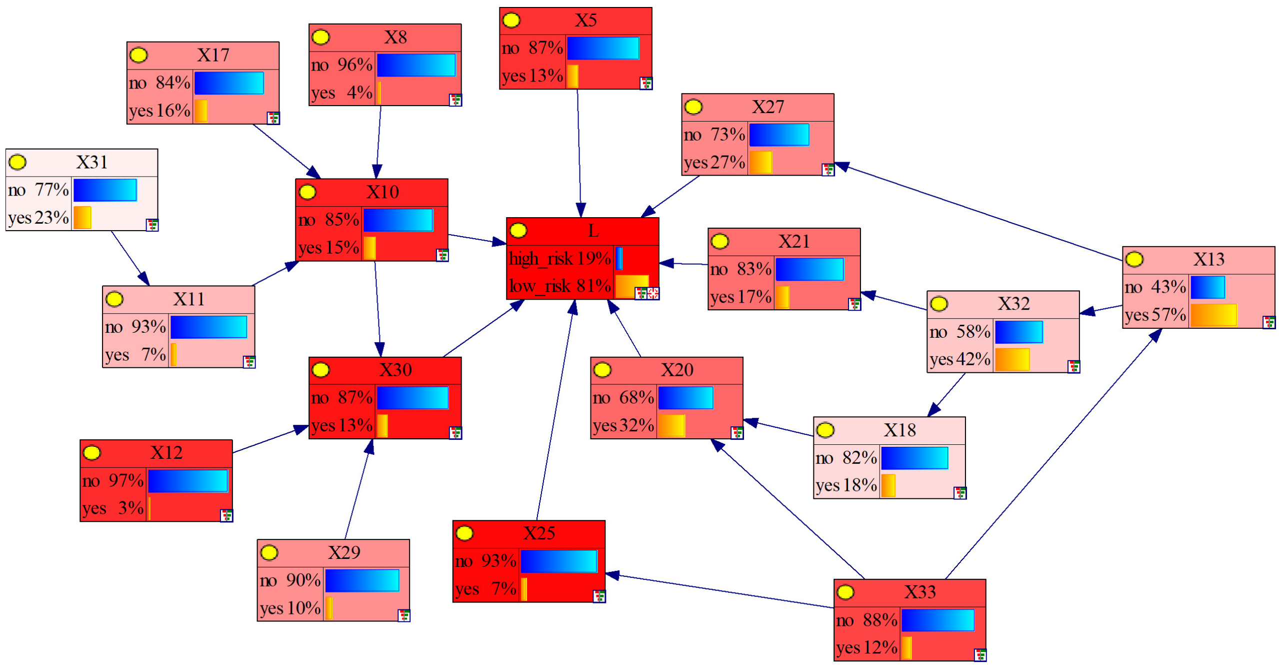

FIGURE 9 | Bayesian network sensitivity analysis.

designing, and constructing at the same time) of construction. For example, an accident investigation report indicates that "the construction project team directed workers to take risks despite the existence of obvious accident hazards in the pit", which is one of the direct causes of the accident.

The Sensitivity Analysis

We used node sensitivity to describe how slight changes in one node's parameters affect the output probability of other nodes in the BN. Identifying key causative factors only by prior or posterior probabilities may lead to inaccurate results, while sensitivity analysis can help for validation (Zarei et al., 2017). In a BN, the high-sensitivity causative factor nodes have a more significant impact on the result node, and by controlling the high-sensitivity causative nodes, the accident risk can be reduced with less cost. **Figure 9** shows the results of Bayesian network sensitivity analysis overall, and the risk factors in the model are highly sensitive. Among them, the six causative factor nodes, i.e., X_5, X_{10}, X_{12}, X_{25}, X_{30}, and X_{33} are in dark red. In other words, it is easier to reduce the risk by controlling the six risk factors of causative factors. The results show that in addition to improving management measures such as prevention and supervision, strengthening monitoring and early warning of the subway construction environment are also important ways to avoid the occurrence of high-risk subway construction accidents.

The Maximum Causation Chain Analysis

By setting "L" in the Bayesian network to "high risk" (**Figure 7**), and then searching for the node with the highest posterior probability of each child node in turn from this node, a complete accident propagation chain can be obtained. Among the child nodes of L, the posterior probability of X_{20} is the largest (50%). By reverse search in turn, the maximum causation chain of high-risk accidents can be obtained, that is, "$X_{33} \rightarrow X_{13} \rightarrow X_{32} \rightarrow X_{18} \rightarrow X_{20} \rightarrow L$". It can be seen that to avoid the occurrence of large and above subway construction accidents, the key is to improve management and government supervision. For example, in the collapse of the Hangzhou Subway, there were problems with the supervision of Hangzhou Metro Group Co., Ltd. by the Hangzhou Municipal Government, which failed to observe that Hangzhou Subway Line 1 was not organized and implemented in strict accordance with the capital construction procedures (X_{33}). The project leader ordered illegal construction and risky operations in order to catch up with the construction schedule (X_{13}), while the supervision unit that should ensure the quality and safety of the project was absent (X_{32}), resulting in serious over-excavation of the foundation pit and serious defects in the support system (X_{20}). Ultimately, the superposition and coupling of multiple factors caused this collapse accident that shocked the world.

DISCUSSION AND CONCLUSION

Due to the significant threat to public safety, social stability, and workers' rights, the subway construction accident has aroused widespread concern and questioning in society (The Central People's Government of the People's Republic of China, 2013). Therefore, it is urgent to identify the key causative factors of subway construction accidents and to control them based on a thorough understanding of the accident mechanism.

A hybrid model based on FTA-BN was constructed in this study, and the following conclusions were obtained through theoretical and empirical analyses:

(1) A total of 33 essential indicators affecting subway construction accidents were identified through FTA and can be classified into five dimensions, namely, worker factors, equipment factors, environmental factors, organizational management factors, and safety culture factors.
(2) The correlation between the causative factors and the severity of subway construction accidents was established. The correlation analysis shows that there are 17 risk factors related to the severity of subway construction accidents. Among them, broader human errors, such as the lack of monitoring by government department staff, risky decisions by leaders, or even the lack of communication between two enterprises of the project team, play an important role. Therefore, in addition to focusing on preventing unsafe behaviors of frontline workers, subway construction practitioners should further investigate the root causes of accidents in order to seek interventions.
(3) A PC-EM-BN model was developed for the causal derivation and prediction of high-risk subway construction accidents. Through reverse reasoning, it is inferred that the key causative factor most likely to cause accidents is the factor "Management's lack of attention to safety production." Sensitivity analysis shows that the control of the six risk factors "X_5, X_{10}, X_{30}, X_{12}, X_{25}, and X_{33}" often achieves maximum results with less effort. Besides, maximum causation chain analysis shows that government supervision will play a significant role in reducing the probability of high-risk accidents, which is also confirmed by some studies (Xu, 2009; Yang et al., 2011; Bu and Li, 2021). Hence, government-related departments need to make more efforts in improving the design of the safety production supervision system, strengthening the communication and inspection with enterprises, etc.

In conclusion, subway construction, as a kind of typical public infrastructure construction, often involves more complex social environments and a wider range of stakeholders. It means that the accident causation is more complex. However, the studies available are still insufficient to explore the causal mechanisms of such accidents. Our study aims to propose a basic framework for subway construction practitioners through the combination of accident causation models and FTA, and expands the application scope of the BN to quantitatively predict the probability distribution of subway construction engineering safety performance. This is a meaningful attempt to combine accident causation theories and accident data for analysis, which also has significant practical implications for the security sector to formulate risk control policies. However, several limitations still exist. First, this is an attempt to analyze the causation of subway construction accidents in the Chinese context, and there is no accessible comparative analysis of related studies to validate the results. We hope that our findings will motivate researchers to further focus on construction safety management in related fields. Besides, the knowledge of practical and theoretical experts familiar with subway construction has been used relatively insufficiently in this study, which is planned to supplement in the further study. Moreover, how to optimize the combination of FTA and the BN is still an issue worthy of exploration and attention when complex factors intertwined. In future study, we will explore other methods to optimize the calculation of CPT during the conversion of FTA to the BN, to further explore the mechanism of risk factors in subway construction accidents.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

ZQ designed the study, structure of the manuscript, and revised the original draft. HY wrote the original draft and performed the analysis. Both authors contributed to this article and agreed to the submitted version.

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The Effect of Safety Leadership on Safety Participation of Employee: A Meta-Analysis

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Recently, the promotion of safety participation (SP) has become a hot spot in behavioral safety research and safety management practice. To explore the relationship between safety leadership (SL) and SP, a theoretical model was established and 33 articles (35 independent samples) on work safety from 2000 to 2021 were selected for a meta-analysis. By evaluating the impact of SL, which incorporates transformational, transactional, and passive leadership styles, on work safety. The results show that SL has a positive impact on both safety climate (SC) and SP. Both safety transactional leadership (STAL) and safety transformational leadership (STFL) positively impact SP, and the impact of STFL is greater, while safety passive leadership (SPL) has no impact on SP. The study establishes that SC plays a partial mediating role between transformational SL and employee SP. Under the condition of a developed economic level or high-risk industry, SL indicated a greater influence on SP. Hence, it is recommended that when enhancing the SP of employees, the influence of the macro environment and SC should not be undermined.

Keywords: safety leadership, safety participation, safety behavior, safety climate, meta-analysis

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INTRODUCTION

Work safety has always been the hot spot in academic research and safety management practice (Gao et al., 2019). Several studies in this field have focused on employees' safety compliance. In as much as safety compliance has a positive impact on an enterprise's work safety, it is not enough to improve the work safety level. By examining data analysis on employee safety behavior and enterprise safety performance, it was found that safety performance still does not reach the ideal level even when enterprises took measures to improve safety compliance (Clarke, 2006; Mullen et al., 2017). Thus, to further improve the level of work safety, the concept of employee safety participation (SP) remains inseparable. Compared to safety compliance, SP is usually considered as employees voluntarily participating in safety-related activities, such as attending safety meetings, taking the initiative to put forward safety improvement suggestions, helping co-workers to stay away from risks, and so on. In this regard, many studies have recognized the significant role of SP (Gunningham, 2008; Liu et al., 2020; Yang et al., 2021). Notably, SP can not only facilitate the implementation of enterprise safety management but also can reduce safety accidents (Wu et al., 2008). Considering the unique characteristics of grassroots employees, who are most directly related to production activities, employees themselves are likely to be more closely related to the involvement in safety-related activities, hence the positive effect of employee SP on enterprises may be greater.

Through the development of economies and the current interest in practicing safety management, a few safety leaders have realized the importance of SP, with some in full swing to take top-down actions that can improve and better safety performance as a whole. Temporarily, the theoretical value of SP research has gradually been revealed, as research that attempt to explore the influencing factors of SP has increased. Most safety-related studies choose to study the antecedents of SP from the internal factors of the organization, and one of the variables which stood out is safety leadership (SL). This is because the safety leader in the top decision-maker of the enterprise's safety production management. The behavior of the safety leader is directly related to the organization's safety production, which can guide the behavior of employees and have a great impact on the enterprise's safety environment (Day and Miscenko, 2016; Jiang et al., 2017). Deluga (1992) pointed out that leaders' behaviors such as humanistic management and efficient work, can promote the formation of a high-quality relationship between leaders and employees, so as to stimulate employees' interest in work and achieve higher goals. As safety leaders are the main superiors of grass-roots employees, their tremendous role in accident prevention remains very critical. Safety leaders can as well influence employees' behavior through value shaping, vision incentive, humanistic care, and innovation drive (Avolio et al., 2009).

In as much as the concept of SL has widely been preached. With the deepening of theoretical research, more variables were involved, including safety climate (SC), safety motivation, and so on. However, with the increase in the number of relevant studies, the differences are becoming larger and larger, and different researchers have drawn different conclusions. Considering the differences in the relationship between SP and SL researchers have attempted to carve different understandings of SL and SP, hence, dividing the concept into several dimensions. For instance, a study by Smith et al. (2016) showed that safety passive leadership (SPL) has a negative influence on SP, while on the contrary, Xue et al. (2020) thought the direction should be positive. Be as it may be, the research samples are based on different countries, different industries, and different times, and may account for these discrepancies. In a study on the construction industry in the United Kingdom (Conchie and Donald, 2009; r = 0.38), the correlation coefficient between SL and SP is much lower than that in China (Wu et al., 2008; r = 0.81). Another evidence is the correlation between SL and SP in manufacturing (Oah et al., 2018) is triple that in the chemical industry (Zohar and Luria, 2010). There may be several reasons for the discrepancy, one of which comes from the research background, such as different employee behavior patterns in different economic backgrounds and different industries.

These different conclusions may easily confuse policymakers and researchers (or readers). With the development of safety behavior research and scientific progress, it is important to clarify the differences established in previous research. In this study, the adoption of the meta-analysis method can easily address these discrepancies. As a mathematical tool, the use of the meta-analysis can integrate many single research data, so as to find general conclusions and differences. To complete this integration process, the concepts of SL and SP were clearly defined by reviewing relevant theories and previous research. Second, a new conceptual model was established to further explore the relationship between SL and SP, and find mediators or moderators and the roles that may exist between them. The study therefore presents a review of 33 research findings (35 independent samples) on the relationship between SL and SP within the period 2000 and 2021 and explains the influence of some potential mediating and moderating effects on them. Finally, the research results are sorted out and the conclusions are drawn, practical and effective suggestions to improve employee's SP are as well provided.

THEORY AND HYPOTHESES

Safety Leadership

Safety leadership originates from general leadership theory. Some researchers think that SL is a process of influencing all employees to chase the safety goal of their organization (e.g., Avolio et al., 2009; Wu et al., 2011). Tao et al. (2020) reviewed the theoretical research of domestic and foreign scholars on SL from 1999 to 2019, and sorted out its evolution process. And Wu et al. (2008) also emphasized that safety leaders should have enough leadership skills on safety (e.g., safety knowledge and decision-making ability, etc.), and utilize these skills to improve the whole safety environment. Based on these previous studies, this present study defines SL as an influence process in which the safety leader improves the work safety environment of the enterprise, guides, or requires employees to regulate their own safety behaviors, and helps them obtain the support of the organization to achieve the overall safety goal of the enterprise.

In Omnibearing Leadership Theory, Bass (1985) divided leadership into three different dimensions, namely, transformational leadership, transactional leadership, and passive leadership. By adopting the concept of this theory, this study divides SL into three dimensions, which incorporate safety transformational leadership (STFL), safety transactional leadership (STAL), and SPL. STFL describes a relatively ideal state in which the leader instills confidence and values in followers, motivates others, and describes the vision so that followers recognize and take actions that are consistent with the organization's goals (Barling et al., 1996). STAL refers to the leader monitoring the safety behavior of employees, caring for employees individually, discussing safety issues with employees, and actively managing safety before an accident occurs. SPL includes management-by-exception leadership and laissez-faire leadership (Avolio et al., 1999), and it is related to an event were safety leaders generally do not take the initiative to participate in safety management but rather prefer to take action after the occurrence of serious safety problems or accidents, and severe punishment for those who made mistakes.

Safety Climate

The concept of SC was first proposed by Zohar (1980) to reflect the perception of the organization's safety environment by the members of the organization. Based on the theory of organizational behavior, its content is gradually enriched (Guldenmund, 2000). The important role of SC had been widely recognized, and it became a variable that can represent a unique safety feature of an organization and not be ignored to measure the safety situation of enterprises (Mullen, 2004). Broadly speaking, a SC can represent all the factors within an enterprise that are related to the safety environment, which includes both the "hard" and "soft" part (Kalteh et al., 2021). But this general description is not conducive to scientific research, so researchers prefer to reinterpret the SC based on their understanding. In other interpretations, the SC is regarded as a variable almost equivalent to the safety culture, and it is defined as a current reflection of safety culture (Mearns et al., 2003). However, a SC focuses more on environment and perception, and some factors that do not form a fixed culture can also be considered in the SC (Casey et al., 2017). Though there are indeed a lot of overlaps between these two variables, and some researchers continue to use safety culture to represent SC, this study still holds the view that they are two independent variables. Thus, based on the consensus of previous studies, safety communication between the safety leader and the employees, the safety concern of the safety leader to the employees, and the dissemination of safety concepts can all be regarded as the standard to measure the safety climate (Alruqi et al., 2018). This study, therefore, defines the SC as the common perception of internal personnel on organizational safety features, which is also part of the consensus of most researchers.

Safety Participation

The concept of SP was first proposed by Griffin and Neal (2000), which refers to the behavior of employees voluntarily participating in safety-related activities and attending safety meetings. They further enriched the scope of SP, except the voluntary participation behavior activities, which include helping co-workers solve the problem of work safety and taking advice from superiors to help improve the safety environment level in companies (Neal and Griffin, 2006). However, with the increasing number of researchers in this subject area, some variables with similar content such as safety citizenship behavior, safety extra-role behavior, and so on appeared. Safety citizenship behavior emphasizes the result of this behavior is beneficial to the organization, but the safety extra-role behavior emphasizes that this behavior is non-post-responsibility, and employees have the willingness to take the initiative. Although the definitions of these variables are slightly different, they have roughly the same meaning, which is they all emphasize that in addition to obeying the requirements of the enterprise and following the safety rules and regulations, employees voluntarily and actively make safety behaviors conducive to the safety performance of the organization. To make the definition of SP clearer, Curcuruto et al. (2015) have made a more detailed division of it. SP can be divided into safety pro-social behavior and safety initiative behavior according to the object of an action. Pro-social safety behavior refers to the social behavior among grass-roots employees, including help, advice, and protection. Safety initiative behavior refers to the spontaneous behavior of employees, including those who actively participate in safety training to improve the safety level of the working environment (Curcuruto et al., 2015). In other words, SP describes a behavior that does not directly improve workers' personal safety behavior, but what indirectly makes contributions to the change of the safety environment of the enterprise (Martínez-Córcoles et al., 2012). Like Martínez-Córcoles (2012), when defining SP, quite a few researchers also choose to describe characteristics and functions.

Based on the definition of previous researchers (Neal and Griffin, 2006; Curcuruto et al., 2015; Curcuruto and Griffin, 2018), this study defines SP as the behavior of grass-roots employees to voluntarily participate in the work safety of an enterprise, such as participating in safety activities, attend safety meetings, taking the initiative to put forward safety improvement suggestions, and helping co-workers to stay away from risks among other safety-related behaviors.

The Influence of Safety Leadership on Safety Climate

Earlier studies on the relationship between general leadership and organizational climate speculated the relationship between SL and SC, and then proved the existence of such relationship through empirical research. Krause (2004) believed SL can improve the safety awareness of employees and strengthen the SC of the organization. Kapp (2012) asserted that SL significantly affects SC and indicated that the leadership practice of daily interaction and guidance with employees can effectively improve SC.

Subsequent studies gradually revealed the relationship between different leadership styles and SC. According to leader's safety behavior, Du and Sun (2012) divided SL into two dimensions. Then, by proving every leader's safety behavior is related to the SC, he draws that two styles of SL are both related to the SC. Conchie (2013) found that transformational SL can improve employees' perception of the SC. In other papers (e.g., Den Hartog et al., 1997; Clarke, 2013; Shi, 2021), researchers made comparative studies on the relationships between STFL and STAL with other variables and concluded that transformational leadership has a more significant impact on SC. On the contrary, because SPL is generally considered as a less effective style of leadership behavior (Berry et al., 2007), there are few relevant studies related to it. Bass's leadership theory, however, argued that SPL should bring passive influence to the organization. But in the study of Kelloway et al. (2006), he put out an unexpected conclusion, indicating that passive leadership contributes incrementally to the prediction of safety-related variables. Nonetheless, the conclusion of the majority of articles maintained the original judgment. Jiang and Probst (2016) found that STFL strengthened SP whereas SPL weakened it. In a recent study from China, safety-specific passive-avoidant leadership negatively affects the safety compliance behavior, which is not conducive to the safety environment of enterprises (Liu et al., 2021). Therefore, we similarly expected that:

H1: Safety leadership is positively related to safety climate.
H1a: Safety transformational leadership is positively related to safety climate.
H1b: Safety transactional leadership is positively related to safety climate.
H1c: Safety passive leadership is negatively related to safety climate.

The Influence of Safety Leadership on Safety Participation

Leadership has been identified as an important factor that influences SP. SL can enable employees to participate in the work of the enterprise more actively and efficiently so as to make them responsible for the work safety of the enterprise (O'Dea and Flin, 2001). Hofmann et al. (2003) found that in the army when leaders show concern for their employees, employees are more likely to do safety extra-role behaviors to show positive feedback to their leaders. In the manufacturing industry, Clarke and Ward (2006) found that the effective implementation of safety goals by leaders has a significant direct positive impact on SP. Similarly, the same results have been found in eastern countries (e.g., Bian et al., 2019; He et al., 2021). That is to say, under different national and industrial backgrounds, SL is related to SP. Therefore, we put forward the hypothesis that SL is positively related to SP (H2).

Like the impact of SL on the SC, different leadership styles and leader behaviors both have different influences on the SP of employees. Both transformational leadership and transactional leadership can play a significant role in SP, but the effect of transformational leadership is more obvious (Clarke and Ward, 2006; Mullen et al., 2017). In addition, when leaders strictly abide by and implement the safety management system, they can improve employees' sense of belonging to the organization and promote the formation of internal consensus (Wu et al., 2008). However, Zohar (2002) firstly found that the impact of SPL on safety behavior is opposite to transformational leadership and transactional leadership. In addition, Mullen et al. (2011) found that passive leadership has a negative impact on SP. Thus, we predicted that:

H2: Safety leadership is positively related to safety participation.
H2a: Safety transformational leadership is positively related to safety participation.
H2b: Safety transactional leadership is positively related to safety participation.
H2c: Safety passive leadership is negatively related to safety participation.

The Mediating Role of Safety Climate Between Safety Leadership and Safety Participation

A positive SC can promote the employees' safety behavior, reduce risks, and improve safety practices (Felknor et al., 2000), and it can also promote employees to actively discuss safety issues and consequently improve employees' SP significantly (Hon et al., 2014). The mediating role of SC in the relationship between leaders' behavior and employees' behavior has also been supported in many empirical studies (Barling et al., 2002; Clarke and Ward, 2006; Kelloway et al., 2006). In the subsequent empirical research on SP, similar conclusions were obtained. Lu and Yang (2010) believed that enterprise safety leaders have an indirect influence on safety behavior through the mediating role of the work atmosphere. Lee et al. (2019) found that SL, SC, and SP were related to each other, and SC played a mediating role in them. Abdullah et al. (2021) showed that SL affects SP through the mediating role of SC and safety motivation. Therefore, SC can not only directly affect SP but also play a mediating role between SL and SP, hence hypotheses 3 and 4 are proposed.

H3: Safety climate is positively related to safety participation.
H4: Safety climate mediates the relationship between safety leadership and safety participation.

The Moderating Role of Economic Level and the Industry Risk Degree

According to the theory of leader-member exchange (LMX), the exchange relationship between leaders and members is different in the different social backgrounds (Dulebohn et al., 2012). Moreover, under the infiltration of the organizational environment, people's internal and external environment will be integrated, and the integration result will interfere with employees' behavior (Zhang et al., 2010). To reduce the research error, two moderate factors (economic level and industry risk degree) were selected to explore whether there is a moderating effect of SL on SP. Different economic levels may lead to different impacts of SL on employees' SP (Nahrgang et al., 2007). At a high economic level, the maturity of enterprises and the education level of employees are higher. Generally speaking, enterprises in developed countries pay more attention to work safety and have better safety management. Chen and Li (2019) proposed that people's behavior types correspond to cognitive types, which explains that employees with good knowledge levels and learning abilities tend to be well-behaved. However, for some enterprises in developing countries not only is the safety management poor but also the employees' safety awareness is low. Therefore, in places with lower economic development levels, employees have more habitual violations and it is more difficult to improve employees' SP. On the other hand, the industry risk level will also have an impact on the relationship between SL and SP. Special operators in high-risk enterprises generally have additional safety training, and if they operate incorrectly, serious consequences may be caused. So employees in high-risk industries are more cautious and have better safety performance (Lingard, 2002). On the contrary, people in low-risk industries may ignore SP because the improvement of SP has a less obvious effect on improving safety performance. Hypotheses 5 and 6 are proposed as,

H5: Economic level plays a moderating role in the relationship between SL and safety participation.
H6: Industry risk degree plays a moderating role in the relationship between safety leadership and safety participation.

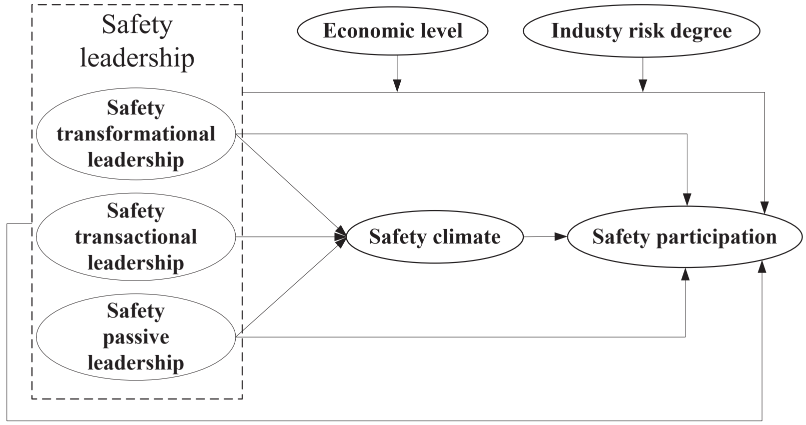

FIGURE 1 | Conceptual model.

The final conceptual model is shown in **Figure 1**.

METHODS AND SAMPLES

Literature Search

To ensure that the samples are not missed, three rounds of selection and two methods are used. The first round of selection was done manually. After reading several papers, a general topic scope and a clear selection standard were determined.

Next, a computerized search in Web of Science, Science Direct, and CNKI was used to infiltrate published articles, which include SL (styles), transformational leadership, transactional leadership, passive leadership SC, SP, safety citizenship behavio(u)r or safety behavio(u)r between 2000 and 2021. In addition, for preventing missing any possible samples, we did a manual re-search of main researchers and major journals such as safety science, accident analysis, and prevention in work safety.

After these articles are collected, the third round of selection begins. Studies identified must satisfy 4 demands at the same time. First, all of them must include at least two of the three aspects among SL, SC, and SP; second, all data must be measured at the individual level and drawn from occupational samples; third, each study that was searched from databases must record publish date, effect sizes on variables of interest (correlation coefficients, t-value or p-value), sample sizes, and other reliable information; last, for the literatures repeatedly published, the data shall be subject to the literature containing more variables.

In the end, 35 independent samples (N = 15749) from 33 articles were selected for this study, and the detailed information is shown in an **Supplementary Appendix** at the end of this paper. The sampling distribution of the effect size of each study followed the normal distribution with known sampling variance, which is in line with the basic conditions of meta-analysis.

Coding for Studies

Considering that the expressions of SL, SC, SP are different in various studies, the search scope of relevant keywords was expanded in this study to ensure the accurate identification of variables. The main codes are shown in **Table 1**.

In the coding process, there are still many ambiguous words. According to the definition of variables in this article and the suggestions of experts, they are encoded as variables with the closest meaning or deleted, which are not listed here because of their low frequency.

Then, each sample is used as a data unit. The author, year, sample size, and effect value were encoded into comprehensive

TABLE 1 | Coding for studies.

Variable	Dimension	Main code
Safety leadership	Safety transformational leadership	Safety-specific transformational leadership
		Safety inspiration
		Rational persuasion
		Safety vision empowering leadership
	Safety transactional leadership	Safety-specific transactional leadership
		Safety monitoring and control
		Personal safety concerns and consultations
		Management by exception active
	Safety passive leadership	Safety passive leadership management by exception passive
		Laissez-faire
Safety climate		Safety culture
		Perceived safety climate Safety attitude of managers Management commitment to safety Managerial safety values
Safety participation		Worker's cooperation on safety
		Feedback and advice on safety
		Safety citizenship behavior Participate in safety activities Proactive safety behavior

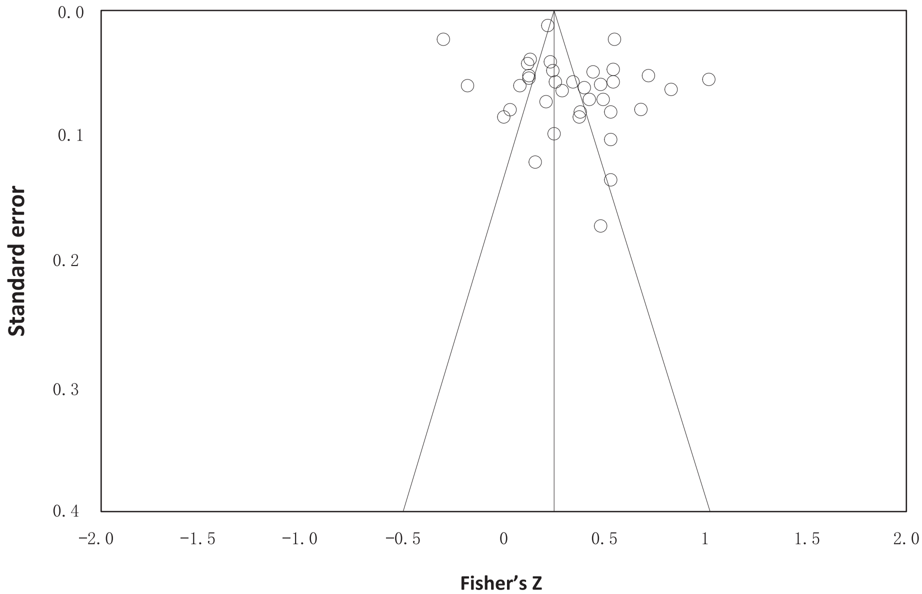

FIGURE 2 | Funnel plot of standard error by Fisher's *Z*.

meta analysis (CMA). If the correlation coefficient between the dimensions of the variable is reported in the study, the final effect value is calculated using CMA software.

RESULTS

Test for Publication Bias

For ensuring the reliability of statistical reanalysis, a publication bias test that included all samples is needed before meta-analysis. Funnel plot and classic fail-safe N are used to test publication bias in this study and the results are displayed in **Figure 2** and **Table 2**. In **Figure 2**, all samples' standard error by Fisher's *Z* is formed into a funnel plot, and in **Table 2**, values that have been calculated by the classic fail-safe *N* method are listed.

In **Figure 2**, except for a few samples, most of the points are concentrated at the top of the funnel plot, which means the sample in this paper is basically not biased. At the same time, most of them are evenly distributed on the left and right sides of the middle line, which means the observed overall effect is robust.

TABLE 2 | The analysis of classic fail-safe *N*.

Items	Value
Z-value for observed studies	36.473
P-value for observed studies	0.000
Alpha	0.050
Tails	2.000
Z for alpha	1.960
Number of observed studies	35.000
Number of missing studies that would bring *p*-value to >alpha	2086.000

Therefore, the funnel plot shows that the selected samples do not have publication bias and meet the conditions for further study.

In the classic fail-safe *N* method, although there is no way to intuitively see whether there is deviation, it can be determined according to the size of the data.

After comparison and identification, the data in **Table 2** reprove this study has no publication bias. In the classic fail-safe *N*-test, the bigger the number of missing studies, the more reliable the conclusion of the meta-analysis is. When $p = 0.000$ and $\alpha = 0.05$, the number of missing studies that would bring a *p*-value bigger than alpha is 2086. In other words, to reverse the conclusion of this study, at least 2086 opposite or useless related studies are needed. During the literature search, it is impossible to find such a large number of samples, there was no publication bias in this paper. Thus, the scientific nature of the research is guaranteed and this research can be continued.

Test of Heterogeneity

The purpose of the heterogeneity test is to examine the degree of difference between independent studies and to calculate whether it is mergeable. If there has no heterogeneity among these samples, the fixed-effect model should be selected. On the contrary, the random effect model should be selected to optimize the overall effect.

Q-value and I^2 are the common heterogeneity indicators in meta-analysis. When the *Q*-value is bigger than the critical value and I^2 is bigger than 75%, the study is considered to be heterogeneous. Conversely, there was no heterogeneity in this study. The calculated data is recorded in **Table 3**.

According to **Table 3**, when the *p*-value equals zero, both *Q*-value and I^2 are bigger than the standard values (Q-value = 1971.50 > 34, I^2 = 98.28 > 75%), which means

TABLE 3 | Fixed effects and random effects meta-analysis.

Model	Effect size and 95% interval				Z	Heterogeneity				Tau-squared			
	NS	PE	L	U		*Q*-value	df (Q)	*P*	I^2	Tau^2	SE	Variance	Tau
F	35	0.26	0.25	0.28	33.70	1971.50	34	0.00	98.28	0.14	0.06	0.00	0.37
R	35	0.36	0.25	0.47	5.95								

NS, number studies; PE, point estimate; L, lower limit; U, upper limit; SE, standard error.

TABLE 4 | Overall effects of the relationship among SL, SC, and SP.

Relationship	NS	PE	95% CI		*Z*-value	*P*-value	Heterogeneity				SE
			L	U			*Q*-value	Df (Q)	*P*-value	*I*-squared (%)	
SL-SC	18	0.307	0.138	0.459	3.477	0.001	1243.522	17.000	0.000	98.633	0.087
SL-SP	21	0.359	0.246	0.461	5.939	0.000	483.718	20.000	0.000	95.865	0.033
SC-SP	14	0.535	0.442	0.617	9.592	0.000	196.412	13.000	0.000	93.381	0.026

NS, number studies; PE, point estimate; 95% CI, confidence interval around effect size, L, lower limit; U, upper limit; SE, standard error.

TABLE 5 | Test results of model path coefficient.

Relationships	NS	TN	PE	95% CI		*Z*-value	*P*-value	Heterogeneity				SE
				L	U			*Q*-value	Df (Q)	*P*-value	I-squared (%)	
STFL-SC	15	8072	0.531	0.386	0.650	6.296	0.001	741.464	14.000	0.000	98.112	0.078
STAL-SC	7	1641	0.493	0.133	0.738	2.604	0.009	391.6443	6.000	0.000	98.468	0.197
SPL-SC	10	4453	–0.244	–0.450	–0.015	–2.084	0.007	437.5093	9.000	0.000	97.943	0.094
STFL-SP	17	5195	0.456	0.387	0.521	11.420	0.000	136.565	16.000	0.000	98.284	0.013
STAL-SP	13	4574	0.347	0.139	0.527	3.189	0.001	647.213	12.000	0.000	88.146	0.084
SPL-SP	8	2400	0.126	–0.044	0.289	1.458	0.145	120.711	7.000	0.000	94.201	0.034

NS, number studies; TN, the total number involved; PE, point estimate; 95% CI, confidence interval around effect size; L, lower limit; U, upper limit; SE, standard error.

heterogeneity exists. Therefore, the random-effects model should be chosen.

Overall Effect Size Based on Random Effect

Test results of hypotheses between SL, SC, and SP are shown in **Tables 4**, **5**. **Table 4** test the overall relationships and **Table 5** shows more details on the sub-variables of SL. It is worth mentioning that, although several independent samples are contained in one article, it is necessary for one article to only have one index when doing summary analysis. That is to say, several independent samples from the same paper are firstly integrated to calculate a comprehensive correlation coefficient, and then analyzed together with other samples. Basically, each hypothesis takes the same data processing method.

In **Table 4**, all relationships were in the direction hypothesized, and the differences were not significant at the 5% level, therefore, hypotheses 1, 2, and 3 can be considered fully supported. According to the results, SL positively affected SC (H1) (PE = 0.307, $p < 0.01$) and SP (H2) (PE = 0.359, $p < 0.01$); SC is more positively affected SP than SL (H3) (PE = 0.535 > 0.359, $p < 0.01$). This may be because people are more susceptible to the influence of environmental changes. It enlightens leaders not to ignore the importance of creating a better SC when promoting employees' SP. Meanwhile, the hypotheses of H1a, H1b, and H1c are all supported. Both STFL (H1a) (PE = 0.531, $p < 0.01$) and STAL (H1b) (PE = 0.493, $p < 0.01$) had a positive effect on SC, while SPL (H1c) (PE = –0.244, $p < 0.01$) had a negative effect on SC. The same situation applies to other hypotheses: a significant, but smaller, effect size was found in STFL-SP (H2a) (PE = 0.456, $p < 0.01$) and STAL-SP (H2b) (PE = 0.347, $p < 0.01$). However, in the test of H2c, the data were not statistically significant (PE = 0.126, $p = 0.145 > 0.01$). This may be because small sample sizes or SPL is inclined to post-management and does not focus on the behavior process of SP.

Comparing these results, STFL has a stronger impact on SC and SP than STAL, which indicates that STFL may be a more effective leadership style within the company.

The Mediating Effect of Safety Climate

The effect values of path SL-SC-SP and path SL-SP are compared to verify whether SC has a mediating role. After manually filtering, nine articles containing SL, SC, and SP were selected. In the range of error allowable, if the effect of path SL-SC-SP is more obvious than that of SL-SP, SC is considered to have a mediating effect. As can be seen from the data in **Table 6**, *p*-value is statistically significant in both random effect models ($p = 0.000 < 0.01$), and the value of the PE effect is bigger in path

TABLE 6 | The mediating effect of safety climate.

Path	TN	NS	PE	95% CI		*Z*-value	Heterogeneity				SE
				L	U		*Q*-value	Df (Q)	*P*-value	I-squared (%)	
A: SL-SC-SP	6492	9	0.357	0.143	0.539	3.189	224.644	8	0.000	96.439	0.067
B: SL-SP			0.331	0.157	0.485	3.634	235.755		0.000	95.758	0.047

NS, number studies; PE, point estimate; 95% CI, confidence interval around effect size; L, lower limit; U, upper limit; SE, standard error.

TABLE 7 | Results of moderators with subgroup analysis.

Variable	Category	NS	TN	PE	95% CI		Test of null (2-Tail)		Heterogeneity				SE
					L	U	Z	*P*	*Q*-value	Df (Q)	*P*	I^2 (%)	
Economic level	Developed	24	12471	0.218	0.201	0.234	24.616	0.00	1633.999	23	0.00	98.592	0.084
	Developing	11	3278	0.425	0.397	0.453	25.882	0.00	197.529	10	0.00	94.937	0.032
Industry risk degree	High-risk	22	7055	0.465	0.447	0.483	42.133	0.00	568.289	21	0.00	96.305	0.035
	Low-risk	13	8694	0.080	0.059	0.101	7.449	0.00	708.361	12	0.00	98.306	0.084

NS, number studies; TN, the total number involved; PE, point estimate; 95% CI, confidence interval around effect size; L, lower limit; U, upper limit; SE, standard error.

SL-SC-SP (0.357 > 0.331), which means SC plays an intermediary role in the relationship between SL and SP. The mediating effect of SC exists, and so H4 is supported.

The role of a good SC between employees and leaders is like glue, which can increase the communication of safety information and reduce potential conflicts. SC should be highly valued in daily safety management. Leaders can create an environment that encourages employees to report safety issues and deal with them in time, so a positive SC can be formed gradually.

Moderator Analysis

In the conceptual model, two moderators are introduced in the study of the relationship between SL and SP: economic level and industry risk degree. Based on different types of work, samples are divided into high-risk industry (such as coal mines, chemistry, oil, and construction) and low-risk industry (such as army, service, trade a mixture of industries, and unknown industry) groups. Then, following the international standard, these samples were reclassified into developed countries (or regions) and developing countries (or regions). Meta subgroup analysis was performed, and the results are shown in **Table 7**.

Indeed, both two variables have moderating effects, so H5 and H6 are supported. The influence of SL in developing economies (PE = 0.425, $p < 0.01$) on SP is greater than that in the developed economy (PE = 0.218, $p < 0.01$), and the influence of SL in high-risk industry (PE = 0.465, $p < 0.01$) on SP is obviously greater than that in low-risk industry (PE = 0.080, $p < 0.01$).

Since most enterprises under the developing economic level are pyramid-shaped organizations, the whole environment is more traditional, so safety leaders have a greater influence on employee behavior than under the developed economic level. Moreover, in high-risk industry, the dangers of work makes employees pay more attention to work safety, and they are more likely to make behavioral changes under SL.

DISCUSSION

Discussion of Results

When people just study the influencing factors of SP, they often continue the previous research idea of safety behavior, that is, they focus on the external influencing factors, especially the influencing factors within the organization. These studies are basically similar in terms of the theoretical basis and research process, but their conclusions are dissimilar. So this study used meta-analysis to examine the differential effects of SL (including STFL, STAL, and SPL), and SC on SPL, including the effect of SC as a mediator. Furthermore, the moderating effect of economic level and industry risk degree were examined.

Discussion of Results on the Influence of Safety Leadership on Safety Climate and Safety Participation

Like most previous studies, the impact of SL on SC is positive and significant, and different dimensions under it show different influences on SP. Except for SPL, which showed significant negative effects, the other two SL styles showed positive effects. In addition, compared with the STAL, the results showed that the STFL has stronger promotion and smaller statistical point estimate bias on the SC. This provides an idea for improving the overall safety environment of enterprises.

Safety leadership was found to have a valid and generalizable relationship with SP, as well as its three dimensions (STFL, STAL, and SPL). As a whole, SL leads to higher levels of SP, and both STFL and STAL have made contributions in this relationship. In particular, the more transformational the leadership is, the greater the improvement of SP will be. Unfortunately, the hypothesis about SPL inhibits SP is not supported. As mentioned above, it is possible that this is a matter of sample selection, but it is more likely that different people react differently to post safety management. Some employees choose to take active safety activities on workdays because they are afraid of the severe management and punishment of their leaders after safety accidents, while other employees do not care about SP because of the loose management of the leaders on workdays. This also provides a suggestion for us to study the influence between SPL and SP in the future. The influencing factors of SP should be considered comprehensively according to the different characteristics of research samples.

Discussion of Results on the Mediating and Moderating Effect

The results prove the mediating role of SC between the relationship of SL and SP. SL can indeed improve the overall environment of the organization. As for the SC, which is an aspect of the organizational environment, it will have an imperceptible impact on the employees in this environment, that's why the SC–SP relationship has the same direction as SL–SC. Kalteh et al. (2021) points out that SC plays a crucial role in enterprises, and there is an interaction between SC and safety behavior. And whether leaders or employees, one of the results of behavior improvement is that the overall safety environment and safety performance of enterprises have been improved to a higher level (Kalteh et al., 2021). The mechanism of this interaction still needs to be further verified, but it suggests the possibility that the safety atmosphere plays more roles than mediating role.

Moderator analysis indicates that both industry risk degree and economic level have a significant effect on the overall effect, and the moderating effect of economic level is more significant. Therefore, when safety leaders improve SP, they should think more comprehensively, because SL and improvement of the social-economic environment are both important.

Limitations

Although following the scientifically and prudent studying steps and striving for perfection, limitations still inevitably exist. First, samples may be missing. As the whole study takes a long time, the gap between the end time of sample screening and the writing time is nearly half a year, so the latest sample may not be included. In addition, in the second round of selection, only mainstream English databases were used, and most of the selected samples were high-level articles, excluding ordinary journals in non-English speaking countries. Second, compared with the number of studies on other kinds of safety behaviors, the number of SP is small. And many data in the meta-analysis have a cross-sectional nature, which means that although several hypotheses are supported in this paper, the direction of the results shown in the model may not be the real direction of the relationship between variables (Clarke, 2006). To adjust it requires further longitudinal testing. However, from the fact that the results of this paper are consistent with most studies, there may be no deviation. Third, individual behavior is the result of the interaction between internal personal factors and external environmental factors (Bandura, 1986; Locke and Bandura, 1987). Therefore, the actual model of SL–SC–SP may be much more complex, and it does not eliminate the possibility that some potential moderators may be ignored. It can be boldly assumed that national culture and personal characteristics will have a certain impact on employees' SP. Similarly, social and cultural background and leadership characteristics will also affect SL. With the deepening of research, researchers should consider more comprehensively and gradually optimize the SL–SP conceptual model to make it more realistic.

Implications

This article makes certain contributions. First, this study combs previous studies and makes the definition of SL and SP clearer. For example, it describes the theoretical development history of SL and explains why it is defined as three dimensions (STFL, STAL, and SPL). The similarities and differences between SP behavior and other variables (such as safety citizenship behavior and safety extra-role behavior) are also pointed out. The emerging new definitions and dimensions are a generalization and re-understanding of the consensus of most studies, which is helpful for researchers to understand relevant concepts quickly.

Second, the conceptual model of SL–SP was formed, and the inconsistent conclusions in previous studies were clarified through meta-analysis. Such as STFL does have a more significant impact on employees' SP than safety transactional leadership and the relationship between SPL and SP was not supported. To a certain extent, these findings may be helpful for enriching the theoretical research in the field of work safety and providing a theoretical guidance for future research.

Third, this article can also contributes to the practice of safety management. By analyzing the relationship among SL, SC, and SP, as well as the role of two moderating variables (economic level and industry risk degree) in the SL–SP relationship, a way to improve SP is revealed. The results suggest that enterprise safety leaders can choose to prefer transformational leadership to improve employee SP and improve the internal SC in combination with the industry risk degree and the economic level of the country where the enterprise is located.

CONCLUSION

This study revealed the inner relationship between SL and SP and identified indirect mechanisms, such as the mediating effect of SC and the moderating effect of economic level and industry risk degree. A total of 35 records related to SL and SP were extracted from 33 papers published in the last 21 years. A model of how different SL styles related to SP was proposed and tested *via* a meta-analysis of CMA software.

The analysis results showed that SL has a positive impact on SC and employees' SP and the latter's impact is stronger. Compared with safety transactional leadership, STFL has a more significant impact on employees' SP. However, the relationship between SPL and SP was not supported. SC plays a partial mediating role between transformational SL and employee SP. Again, the impact of SL on SP is affected by the economic level and the risk degree of the operating industry. Under the condition of a developed economic level or high-risk industry, SL has a greater influence on employees' SP.

These findings may contribute to the future development of safety management theory and practice, especially in optimizing SL, improving employee SP, and promoting the improvement of safety performance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

LZ: conceptualization and methodology, original draft preparation, writing—reviewing and editing, and data acquisition and analysis. DY: supervision and sponsor. SL: supervision, sponsor, and editing. EN: data acquisition and editing. All authors contributed to the article and approved the submitted version.

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The Evolutionary Game of Post-conflict Management for New Generation of Construction Workers in China: The Mediating Role of Foremen

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The emotional perception of the new generation of Chinese construction workers is becoming stronger, and the traditional punishment-type management model is gradually failing. In order to address the safety hazards caused by the negative emotions generated after workers' conflict events, the motivation of workers to actively participate in the construction of safety climate is increased, and the safety performance of construction projects is enhanced. This paper introduces emotional event theory to assess workers' psychological perceptions and uses foreman as an intermediary for safety management to analyze the decision-making process between managers and work-groups in the safety management process. By establishing a tripartite evolutionary game model of manager, foreman, and worker, the evolutionary differences among the three parties when the manager is strict or appeasing are examined. The results of the study showed that managers who showed appeasement were more effective than those who showed stringency in accomplishing the safety goals of the project. As the workers' psychological perception index increased, workers were more inclined to adopt aggressive strategies, and their behavior was more influenced by their own moral identity as well as the foreman's attitude under the manager's appeasement attitude. This study can provide managers with suggestions on how to handle the situation after a conflict, which can help regulate the behavior of construction teams and eliminate safety risks.

Keywords: post-conflict processing, evolutionary game theory, affective event theory, foreman influence, emotional perception

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1. INTRODUCTION

The construction industry has steadily become a high-risk industry due to its complicated operational environment, frequent usage of harmful appliances, and the inherent decentralization and mobility of construction employees (Fang et al., 2006). In China, for example, there were 6,005 catastrophic accidents and 7,275 deaths in the construction industry between 2010 and 2019 (Xu and Xu, 2021). The 2018 report on safety in China (Ministry of Emergency Management of the People's Republic of China, 2018) pointed out the poor supervision of safety hazards by participating parties and the prevalence of construction site violations, which directly lead to accidents. Many of these safety hazards are caused by conflicts and disputes (Harmon, 2003), which can lead to project delays and even casualties if conflicts are not handled properly (Jaffar et al., 2011). Casualties are the most unacceptable tragedy in the construction process, and the repeated safety accidents reflect the failure of safety management and the deficiencies in safety performance. Due to this, safety management has been put at the top of many construction projects. Many research has been undertaken to investigate the important factors that contribute to construction safety risks, and these studies point to the interaction between project managers and construction employees as a key determinant (Shao et al., 2019; Zhou et al., 2019; Li et al., 2021).

As China's modernization process accelerates, the number of building projects grows, and a shortage of construction workers prompts an increasing number of migrant workers to consider the construction industry as a way to make a living (Swider, 2015). In construction projects, however, maintaining a balance between the management team and the construction teams is difficult, the number of workers outnumbers the number of managers, and the managers are unable to maintain constant command and direction, of overall workers. The huge groups of employees are also divided into many smaller teams based on the type of work due to the decentralized and mobility character of construction workers, as well as the technical requirements of construction. The advancement of the construction process necessitates the cooperation of each team, and the restricted construction site and construction supplies can easily lead to conflicts between the construction teams, increasing the risk of injury (Forteza et al., 2022). Especially in work at height, conflict incidents create a discordant safety climate and keep the safety bottom line at an extremely low level (Wong et al., 2016). The concept of safety climate has its roots in organizational culture (Zohar, 1980) and is often used to describe the perceptions and attitudes of employees toward safety issues (Guldenmund, 2000). Because the team is working temporarily and is unfamiliar with each other, post-conflict antagonism is high, the perception of cooperation is low, and cooperative behavior is negative (Liu et al., 2021). Workers' own will may override their safety consciousness under the impact of such emotions, causing them to act in ways that may result in safety incidents (Liu et al., 2020).

Maintaining worker safety awareness as a top priority is a difficult task for safety managers, and a great management strategy is essential. However, research on this problem is far from thorough. Although many studies have been conducted to reduce workers' unsafe behaviors (Smith et al., 2017; Ma et al., 2021), there are fewer dynamic analyses from the perspective of a construction team, in which managers divide all workers into teams and adjust management measures dynamically based on the characteristics of each team and the state of construction safety awareness. Some research findings have proposed influencing construction workers' behavior from a management level perspective (Zhu et al., 2021; Zulu and Khosrowshahi, 2021), these studies only treat workers as a whole, and the constant turnover of shifts in short- and medium-term construction projects makes it difficult to transfer management's organizational characteristics to the construction team, and there is a great deal of uncertainty about whether workers' personalities fit together.

Although accidents in the construction industry are not uncommon, but narrowing the perspective to specific construction projects, the casualty rate of accidents is still a small number compared to the number of employees. Under this premise, workers will subjectively ignore safety risks and take some more convenient but dangerous behaviors. Although the safety manager has overall control over the safety performance of the project, he cannot always pay attention to the construction personnel in the details. Their bounded rationality and incomplete grasp of background information make evolutionary game theory useful in this context. As a result, in order to complement research on the causes and treatments of workers' unsafe behaviors, this study hypothesizes that the factors affecting project safety performance and effective treatment measures will be found under the two attitudes (Strict supervision and Appeasing supervision) of managers following the team conflict event, as well as the constraints and strategies to promote the evolutionary stability of the game, which is the excellent safety performance expected by the stakeholders. The main contributions of this paper are as follows: (1) introducing workers' psychological identity as a tendency indicator for judging workers' unsafe behaviors, and using evolutionary game theory to analyze the mutual influence of safety managers, foremen and workers. (2) Exploring the effectiveness of safety managers' strict supervision and appeasing supervision in treating the new generation of construction workers. (3) To reveal the intermediary role of foreman between safety managers and workers in safety management.

The following are the remaining sections of this paper: The second section of the paper is devoted to a review of the literature. Section 3 examines the game equilibrium and constructs an evolutionary game model based on replicated dynamic systems. The simulation study for various scenarios is presented in Section 4. Then, Section 5 discusses the simulation results and the proposed measures for a safe environment. Finally, in Section 6 we provide our conclusion of the work.

2. LITERATURE REVIEW

Construction-related safety incidents are not unavoidable, and significant progress has been accomplished in recent decades. Interviews, surveys, data mining, and game theory models have all been used to study the parties engaged in construction.

2.1. Unsafe Behavior and Affective Events Theory

At present, many researchers have indicated that workers' unsafe behaviors might have a considerable detrimental impact on safety performance (Mitropoulos et al., 2005, 2009; Choudhry, 2014). And majority of academics are interested in learning more about the reasons for insecure behavior (Wu et al., 2018; Fang et al., 2020). Mazzetti et al. (2020) proposed that construction workers' safety behavior is related to their safety perceptions and knowledge. Yao et al. (2021) reached similar conclusions after analyzing 6,561 tweets about construction safety on Twitter, and in addition, they suggested that the government as an opinion leader can act as a medium for safety knowledge dissemination and raise construction workers safety awareness. These research results analyze the results of external influence on the behavior of construction workers and the ways in which they are affected, but do not pay much attention to the beginning and process of workers' change.

Therefore, some scholars have begun to build simulation models to evaluate the entire process of building accidents in order to better extract the variables that cause accidents and investigate the handling procedures that can help to maintain good safety performance. For construction accidents, Ge et al. (2022) looked at the application of five common accident causation models in China from 1978 to 2018, finding the significant influence of previous modeling research on policy formation, accident investigation and treatment, and safety management measures in the Chinese government. Cabello et al. (2021) further analyzed the various phases of engineering construction to point out the priority of outsourcing variables in accidents and demonstrated the importance of risk assessment.

However, Construction teams are collected temporarily and only work for a limited time in the project due to the mobility and decentralization of construction workers, and there is no close interaction between crews (Fang et al., 2006). Also, construction projects are mostly carried out in resource-limited situations (Du et al., 2021). Conflict events can readily develop between construction teams to vie for resources or seize work locations, and conflict events can cause emotional reactions in individuals, which can further impact their attitudes and behaviors (Weiss and Cropanzano, 1996), increasing the likelihood of safety mishaps (Man et al., 2021).

The core concept of affective event theory is that the events an individual experiences at work affect his or her emotional state, which in turn affects his or her attitudes and behaviors (Weiss and Cropanzano, 1996). Negative events in the workplace are important emotional events that affect employees' emotional state (Bono et al., 2013). Conflict events in construction teams can be categorized as workplace deviant behavior, which is defined as intentional behavior by employees that is detrimental to the organization and other members. This behavior is a specific manifestation of the affective event theory. The affective event theory states that after a dispute arises, the employee's level of moral identification influences his or her emotions and, as a result, his or her subsequent action (Schaumberg and Flynn, 2021). Chen et al. (2020) investigated the attitudes and behaviors of 143 construction workers in the face of family conflict and work environment disruptions, stressing the mediation impact of emotional feelings on work. Employees give greater attention to their own feelings and prefer to make decisions based on their own perceptions, according to Ming and Yue (2018), and the prevalence of deviant behaviors in the workplace is dependent on employees' own perceptions. Kong and Kim (2017) proposed that employees who possess a high degree of psychological mastery have some innovative responses to workplace deviant behavior.

2.2. Impact of Foreman

For construction projects, the construction team is the basic unit of operation. During the construction process, the foreman is the main person who directs the workers as well as communicates. Thus, the construction team leader's leadership abilities will have a direct impact on the team's climate. The team leader's safety knowledge will affect the workers' construction conduct and play an essential role in preventing safety mishaps (Hinze, 1981).

With the accelerated rate of urbanization in China, more and more young migrant workers are entering the construction industry (Chen et al., 2018). Younger workers are less safety-conscious than older workers, have a higher risk of being exposed to dangers, and have a negative opinion of the safety atmosphere (Meng and Chan, 2020). These groups have distinct group characteristics, such as a greater sense of fairness and protection of rights (Franceschini et al., 2016), as well as stronger personalities (Tang et al., 2020). Strong punitive measures (fines or other measures) may not be effective in inducing a change in their consciousness, and the role of opinion leaders is more likely to be flanked by them (Choi and Lee, 2018).

Many scholars believe that accidents occur not only as a consequence of employees' unsafe behavior but also as a result of the team leader's negative attitude toward unsafe behavior, which causes team members to pay less attention to their behavior, resulting in tragedies, whereas the team leader's positive influence will ensure a high level of safety. Wang et al. (2021) proposed that workers' safety responsibilities and safety trust in their supervisors mediated the relationship between employees' beliefs about the mutual fulfillment of their safety obligations with their supervisors and their active participation in safety construction. Xiong et al. (2018) studied the perceptions of 586 scaffold workers about employee influence, applying the idea of opinion leaders to construction safety and proving the powerful influence of team leaders on the typical worker. Kaskutas et al. (2016) evaluated safety performance before and after team leader training and discovered that safety scores improved in all aspects after training, demonstrating that effective education of employees by team leaders plays an important role in reducing safety accidents.

The tendency of workers to follow opinion leaders is noted, but how to use this characteristic effectively becomes a challenge. Workers' strong personalities can counter the strict management of safety managers. As a result, many scholars have begun to study the impact of shifts in safety managers' attitudes toward workers on project safety performance. He et al. (2021a) suggests that excellent leadership and communication skills of safety personnel can create a supportive safety climate at the worksite to improve construction safety performance. He et al. (2021b) proposed that worker-safety manager communication is a key variable in safety performance and illustrates the need for enhanced psychological interventions for workers. Liu et al. (2020) pointed out that when leader-member exchange has high quality, it can effectively inhibit the generation of workplace deviant behaviors. The utility of communication in managing safety among the new generation of construction workers is becoming apparent, and several studies have shown that improvements in safety performance can be achieved through foreman-worker interactions. Kaskutas et al. (2013) evaluated the effect of foreman training in safety communication on improving worker safety performance. Kines et al. (2010) suggested that increased foreman-worker verbal safety communication has a significant and long-lasting effect on safety performance improvement. The weight of enhanced communication management by safety managers through the intermediary role of foremen is called appeasing supervision in this paper.

In summary, the above studies demonstrate the influence of emotional perception on worker behavior and the strong influence of foremen on workers. However, the reduced effectiveness of traditional punitive measures (such as fines, reprimand, etc.) still gives construction companies a sense of crisis, and changes in safety management measures are necessary as factors that can directly affect whether a project is carried out or not.

3. RESEARCH METHODOLOGY

3.1. Description of Research Framework

Observed through the lens of affective event theory, the nature of conflict behavior that occurs between construction crews at the construction site is an extension of the workplace deviant behavior of workers. The close-knit nature of construction crews makes workplace deviant behaviors less about single person-to-single person influence and more about group-based confrontation. During this period, workers are simultaneously influenced by their own emotional perceptions as well as environmental drivers, which are susceptible to adverse effects on the unavoidable synergy in construction.

Nowadays, with highly popular education in China, the new generation of construction workers is becoming more individualized and more sensitive to emotional perceptions. Whether, they are the perpetrators or recipients of workplace deviant behavior, they are often influenced by the intrinsic mechanism of their own emotions to take positive compensatory measures or negative avoidance attitudes in their subsequent work. Positive remedial measures enhance the safety climate, while negative attitudes produce consequences such as reduced motivation, slower work speed, and the development of unsafe behaviors.

For safety managers, they are unable to reach the emotional perception of all workers. Even when they perceive workers' emotions, they let them go out of the traditional handling mindset. The external safety equipment and measures at construction sites are so complete that the mental health of employees has reached a point where it cannot be ignored as a percentage of construction safety. However, safety managers are reluctant to pay in this area and ignore the mental health of their employees.

Foremen are between managers and workers. On the one hand, they are the leaders of workers, and they live with them day and night, and their emotions and behaviors greatly influence workers; on the other hand, they are still workers in the eyes of managers, and their management style has not changed much. It is obviously unreasonable for Foremen, as intermediary figures between workers and managers, to be treated the same as workers.

These three parties have intersecting interests in safety performance and influence each other. For example, workers' unsafe behaviors that create safety hazards increase the supervision of managers. When both the foremen and workers work negatively, safety accidents are highly likely to occur. In addition, the strategies of foremen, workers, and safety managers are not set in stone in dealing with workgroup conflict. Effective management mechanisms and control of the psychological state are the keys to an ideal safety strategy. Maintaining the awareness of workers' safety first, the positive attitude of the foremen infecting the team, and the effective motivation of the manager to the team members.

Evolutionary game theory assumes that humans are not fully rational objects and at the same time do not possess complete background information. In the game equilibrium, the system reflects a dynamic equilibrium. The setting of various parameters and changes in their values affect the strategy choice of each player. In addition, unlike classical game theory, the participants reach the game equilibrium by trial and error during the evolutionary process. Therefore, evolutionary game theory can be a good way to analyze the relationship between the three players. In this paper, we use evolutionary game theory to determine the dynamic equilibrium of safety managers, foremen and workers to find stable constraints and the relative magnitude of influencing factors to achieve excellent project safety performance.

The model framework of this paper is shown as follows: (1) Establish the hypothesis to quantify the strategic gains and losses of the three parties. (2) List the difference between the gain and loss of the three parties under the traditional attitude and the appeasement attitude of managers. (3) Calculate the evolutionary stability of each strategy combination and derive the stability conditions. (4) Conduct simulation to verify the stability of the strategy combinations. The entire model framework is shown in **Figure 1**.

3.2. Model Assumptions

Although conflicting behavior is temporarily harmless, managers and members of workgroups will sense impending danger. When confronted with uncertainty and risk, managers and workgroups display limited rationality and emotional drive, causing them to alternate between "self-interest" and "active participation" resulting in various engagement tactics. In addition, this section defines the game player and strategy in positive and negative terms, proposes parameters that affect the utility of the game player, and constructs the payoff matrix of the post-conflict contextual game based on the literature in **Table 1** and the literature review in Section 2.

The following assumption are proposed based on the relationship between managers, foremen, workers, the theory of emotional events, and the features of the team's role.

Assumption 1: There are two strategic options available to each of the three parties in the game. The probability that the manager will utilize the two strategies of {Strict supervision, Appeasing supervision} is x and $1 - x$, respectively. "Strict supervision" refers to the use of strong punitive measures (e.g., fines), while "Appeasing supervision" refers to giving the foreman psychological pressure through safety education and other means to influence the workgroup members. The foreman's strategy set is {Tough, Lenient}, denoted as the attitude toward the workers with probability y and $1 - y$. Workers are direct

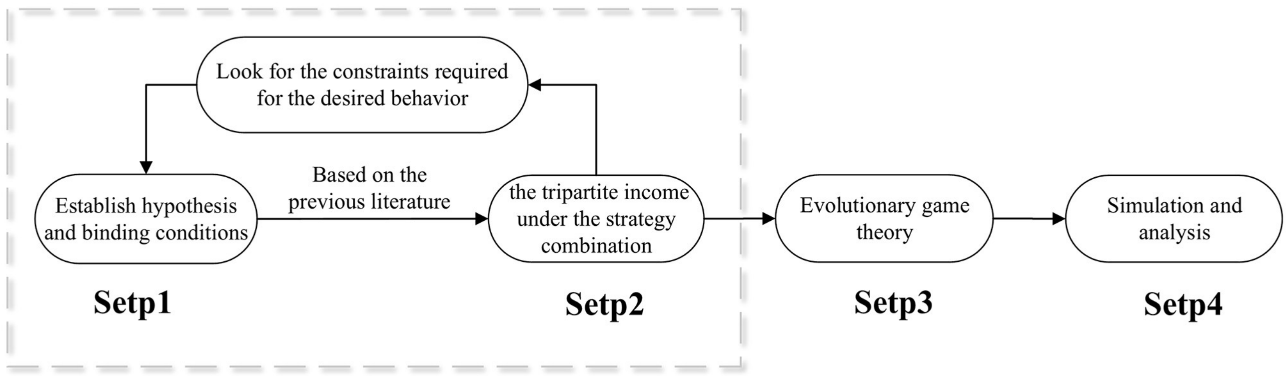

FIGURE 1 | Model frameworks.

TABLE 1 | Review the game and influence of participants on safety performance.

Literature	Players	Strategies	Impact on safety performance
Gao et al. (2020)	Government Enterprise	Active regulation/ compliance	In the case of information asymmetry, companies lack trust in regulatory policies and have a low willingness to comply with safety regulations.
Guo et al. (2021)	Government Enterprise Worker	Encourage/provide/ participate in safety training	It demonstrates the importance of government oversight for companies and workers to participate in safety skills training.
Yun et al. (2021)	Tower crane users maintenance parties supervisors	Regulatory compliance/ strict maintenance/ active supervision	The three parties will select a safety regulatory strategy that is favorable to the tower crane operation when the sum of the penalty amount and safety incentive performance is greater than the safety input cost.
You et al. (2020)	Mine owners safety regulators general miners	Strict inspection/ strict supervision/ compliance with rules	Increasing the intensity of rewards and punishments can quickly reduce the rate of unsafe worker behavior.
Gong et al. (2021)	Mine owners safety regulators general miners	Dynamic/ static supervision	The effectiveness of the government's dynamic regulatory mechanism to improve the efficiency of supervision and improve the initiative of enterprises to participate in the construction of safety.

actors in team conflict, and they have two alternatives for dealing with the post-event safety climate: {Active participation, Passive response}, with a probability of z and $1 - z$.

Assumption 2: Workers acquire guilt after encountering team conflict, according to Schaumberg and Flynn (2021), which impacts their own negative emotions, which in turn influences their job conduct. The moral identity of the workers can have a significant impact on the psychological to behavioral shift. In this game, indicators of moral identity influence the rewards and penalties that workers get. This is expressed in this paper as dissatisfaction A_1 with the tough punishment of the safety supervisor and psychological compensation A_2 for the lenient treatment of the foreman.

Assumption 3: The new generation of construction workers, according to Xiong et al. (2018) and Ni et al. (2020), has a strong sense of individuality and is resistant to harsh punishments; the foreman, as the spiritual leader of the workers, has more control over this group of workers, and the foreman's attitude influences the workers' psychology and behavior. In other words, workers are influenced by the attitudes of both managers and foremen.

Assumption 4: The workers' attitude toward the construction of safety climate affects the probability of safety accidents. The probability of an accident with a positive attitude is α_1, and the probability of an accident with a negative attitude is α_2 ($\alpha_2 > \alpha_1$). The accident will cause huge losses to all three parties. The government will impose a fine of P_1 on the safety supervisor; the construction company will deduct the bonus of the foremen P_2; and the workers will suffer a safety loss of P_3. Under the strict supervision of the safety managers, the two strategies of the foreman represent fines to be borne by himself or by the workers, triggering either praise or dissatisfaction from the workers, expressed as reputation gain or loss R. Under the appeasing management of the safety managers, the forgiving attitude of the foreman needs to bear the pressure from the safety managers K, the cost of tough management is C_2. The two

TABLE 2 | Explain of the parameters.

Parameters	Explain
C_{11}	Management costs for safety managers choosing a Strict supervision strategy.
C_{12}	Management costs for safety managers choosing a Appeasing supervision strategy.
I	Bonuses for safety managers due to good safety climate.
F	Fines issued by the safety manager to the working group.
R	The foreman's reputation is lost or gained.
K	The psychological pressure gained by the foreman choosing the Lenient strategy.
C_2	The management costs by the foreman in choosing the Tough strategy.
P_1	Penalties for safety managers after a safety incident.
P_2	Penalties for foreman after a safety incident.
P_3	The safety loss of workers after a safety accident.
T	The additional cost to workers of choosing an Active participation strategy.
α_1	The probability of a safety incident when workers choose the Active participation strategy.
α_2	The probability of a safety incident when workers choose the Passive response strategy.
A_1	Workers' dissatisfaction with safety manager punishment is influenced by their own moral identity.
A_2	Workers' approval of the foreman's behavior is influenced by their own moral identity.

strategies of the safety managers cost C_{11} and C_{12}, respectively, to manage, and in a good safety climate will receive a bonus I.

With the above assumptions, the parameters and variables of this tripartite evolutionary game model are shown in **Table 2**.

3.3. Model Establishment

The traditional way of safety management is for managers to inspect the construction process and results of workers from time to time. In the process, the manager finds the unsafe behavior of workers or other violations of regulations and takes strong measures such as simple fines. However, managers are lagging behind in dealing with the situation according to the site, and safety hazards bring the possibility of safety accidents once they arise. And tough punishments are difficult to achieve satisfactory results in the face of employees with strong personalities. If managers change the way of handling and do not handle the workers hard and directly, the foremen should play an intermediary role between managers and workers. When the safety manager chooses the Strict supervision strategy, the construction team has to bear the fines from the safety management, and the foreman's attitude determines who pays the fines, and the foreman's and the workers' fear of fines affects their strategy choices. When the safety manager chooses the Appeasing supervision strategy, the substantial fines are transformed into psychological pressure on the foreman, and in this case, the workers' strategy choice is mainly determined by their own moral identity influenced by the psychological compensation to the foreman as well as the safety manager. Enhance safety education and investment to the foreman, let the foreman influence the safety status of workers, and assist the manager to coordinate and manage after the conflict occurs. The foreman is the manager of the workers and a participant in the work, and they can be the first to know the condition of the construction site. Managers can quickly learn from foremen about real-time safe production, quickly calm workers' emotions and adjust management measures (Kaskutas et al., 2016). In this case, the regulatory results are more flexible and effective for the new generation of self-reliant construction workers.

According to the above discussion, combined with literature mining and the actual situation, the tripartite relationship diagram is obtained, as shown in **Figure 2**.

Evolutionary game theory is carried out on the premise that the three parties belong to limited rationality. The strategy choices of the three parties are influencing each other and choosing the most favorable strategy in perception. Both foremen and workers have two strategies to deal with the strict supervision or appeasing supervision of safety managers, which will produce a combination of eight strategies. Based on the above assumptions, the profits and losses of the three parties are calculated under eight strategy combinations.

(1) When the safety manager selects Strict supervision, the foreman selects Tough and the worker selects Active participation. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{11} + (1 - \alpha_1)I - \alpha_1 P_1$. If the foreman chooses to let the workers accept punishment, he will suffer loss of reputation, and the income is $-R - \alpha_1 P_2$. Workers' active participation in safety construction requires additional construction costs, and the income is $-T - F - \alpha_1 P_3$.

(2) When the safety manager selects Strict supervision, the foreman selects Tough and the worker selects Passive response. At this time, the safety risk will increase to α_2. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{11} + (1 - \alpha_2)I - \alpha_2 P_1$. If the foreman chooses to let the workers accept punishment, he will suffer loss of reputation, and his income is $-R - \alpha_2 P_2$. Workers' dissatisfaction with the tough punishment of safety managers will produce A_1 psychological compensation under the workers' Passive response Strategy, and its benefit is $-\alpha_2 P_3 + A_1 - F$.

(3) When the safety manager selects Strict supervision, the foreman selects Lenient and the worker selects Active participation. Safety managers need to pay management costs and possible safety rewards or penalties, and the benefits are $-C_{11} + (1 - \alpha_1)I - \alpha_1 P_1$. The foreman took the fine and received the reputation gain from the workers, which improved his prestige in the workegroup, with a gain of $R - F - \alpha_1 P_2$. The active participation of workers will produce psychological compensation A_2 for the foreman, and the benefit is $-T + A_2 - \alpha_1 P_3$.

(4) When the safety manager selects Strict supervision, the foreman selects Lenient and the worker selects Passive response. At this time, the safety risk will increase to α_2. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{11} + (1 - \alpha_2)I - \alpha_2 P_1$. The foreman took the fine and received the reputation gain from the

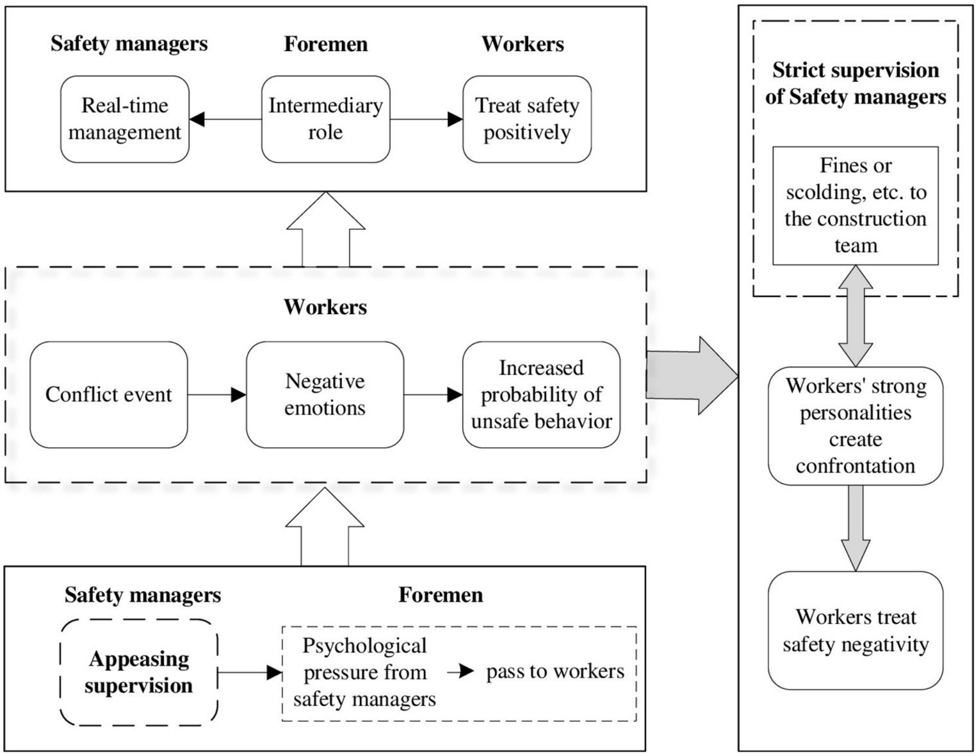

FIGURE 2 | Tripartite relationship diagram.

workers, which improved his prestige in the workgroup, with a gain of $R - F - \alpha_2 P_2$. Workers' dissatisfaction with the tough punishment of safety managers will produce A_1 psychological compensation under the workers' Passive response Strategy, and psychological compensation A_2 for the foreman, the benefit is $-\alpha_2 P_3 + A_1 - A_2$.

(5) When the safety manager selects Appeasing supervision, the foreman selects Tough and the worker selects Active participation. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{12} + (1 - \alpha_1)I - \alpha_1 P_1$. The foreman needs to pay the management cost C_2 and the income is $-C_2 - \alpha_1 P_2$. The worker's income is $-T + A_2 - \alpha_1 P_3$.

(6) When the safety manager selects Appeasing supervision, the foreman selects Tough and the worker selects Passive response. At this time, the safety risk will increase to α_2. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{12} + (1 - \alpha_2)I - \alpha_2 P_1$. The foreman needs to pay the management cost C_2 and the income is $-C_2 - \alpha_2 P_2$. The worker's income is $-\alpha_2 P_3 - A_2$.

(7) When the safety manager selects Appeasing supervision, the foreman selects Lenient and the worker selects Active participation. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{12} + (1 - \alpha_1)I - \alpha_1 P_1$. The foreman needs to bear the psychological pressure from the safety manager, and the profit is $-K - \alpha_1 P_2$. The worker's income is $-T - \alpha_1 P_3$.

(8) When the safety manager selects Appeasing supervision, the foreman selects Lenient and the worker selects Passive response. At this time, the safety risk will increase to α_2. Safety managers need to pay management costs and possible safety rewards or penalties, and their benefits are $-C_{12} + (1 - \alpha_2)I - \alpha_2 P_1$. The foreman's income is $-K - \alpha_2 P_2$. The worker's income is $-\alpha_2 P_3$.

The predicted returns of the three groups under various situations were computed using the description in **Table 3** and the evolutionary game analysis method that replicates the dynamics.

The expected payoffs for the manager's choice of the "Strict supervision" or "Appeasing supervision" strategy set are V_x and V_{1-x}, respectively, and the average expected payoff is V_1, then we have:

$$\begin{aligned} V_x &= yz(-C_{11} + (1 - \alpha_1)I - \alpha_1 P_1) \\ &+(1 - y)z(-C_{11} + (1 - \alpha_1)I - \alpha_1 P_1) \\ &+y(1 - z)(-C_{11} + (1 - \alpha_2) - \alpha_2 P_1) \\ &+(1 - y)(1 - z)(-C_{11} + (1 - \alpha_2) - \alpha_2 P_1) \end{aligned} \tag{1}$$

$$\begin{aligned} V_{1-x} &= yz(-C_{12} + (1 - \alpha_1)I - \alpha_1 P_1) \\ &+(1 - y)z(-C_{12} + (1 - \alpha_1)I - \alpha_1 P_1) \\ &+y(1 - z)(-C_{12} + (1 - \alpha_2)I - \alpha_2 P_1) \\ &+(1 - y)(1 - z)(-C_{12} + (1 - \alpha_2)I - \alpha_2 P_1) \end{aligned} \tag{2}$$

TABLE 3 | Payoff matrix.

	Strict supervision (x)		Appeasing supervision ($1-x$)	
	Tough (y)	Lenient ($1-y$)	Tough (y)	Lenient ($1-y$)
Active participation (z)	$-C_{11}+(1-\alpha_1)I-\alpha_1P_1$ $-R-\alpha_1P_2$ $-T-F-\alpha_1P_3$	$-C_{11}+(1-\alpha_1)I-\alpha_1P_1$ $R-F-\alpha_1P_2$ $-T+A_2-\alpha_1P_3$	$-C_{12}+(1-\alpha_1)I-\alpha_1P_1$ $-C_2-\alpha_1P_2$ $-T+A_2-\alpha_1P_3$	$-C_{12}+(1-\alpha_1)I-\alpha_1P_1$ $-K-\alpha_1P_2$ $-T-\alpha_1P_3$
Passive response ($1-z$)	$-C_{11}+(1-\alpha_2)I-\alpha_2P_1$ $-R-\alpha_2P_2$ $-\alpha_2P_3+A_1-F$	$-C_{11}+(1-\alpha_2)I-\alpha_2P_1$ $R-F-\alpha_2P_2$ $-\alpha_2P_3+A_1-A_2$	$-C_{12}+(1-\alpha_2)I-\alpha_2P_1$ $-C_2-\alpha_2P_2$ $-\alpha_2P_3-A_2$	$-C_{12}+(1-\alpha_2)I-\alpha_2P_1$ $-K-\alpha_2P_2$ $-\alpha_2P_3$

$$V_1 = xV_x + (1-x)V_{1-x} \tag{3}$$

The replicated dynamic equation for the manager's behavioral strategy is then:

$$f(x) = dx/dt = x(1-x)(C_{12}-C_{11}) \tag{4}$$

Similarly, the expected benefits of the foreman choosing the "Tough" or "Lenient" strategy set areV_y andV_{1-y}, respectively, and the average expected benefit is V_2, then we have:

$$\begin{aligned} V_y &= xz(-R-\alpha_1P_2)+(1-x)z(-C_2-\alpha_1P_2) \\ &+x(1-z)(-R-\alpha_2P_2) \\ &+(1-x)(1-z)(-C_2-\alpha_2P_2) \end{aligned} \tag{5}$$

$$\begin{aligned} V_{1-y} &= xz(R-F-\alpha_1P_2) \\ &+(1-x)z(-K-\alpha_1P_2) \\ &+x(1-z)(R-F-\alpha_2P_2) \\ &+(1-x)(1-z)(-K-\alpha_2P_2) \end{aligned} \tag{6}$$

$$V_2 = yV_y + (1-y)V_{1-y} \tag{7}$$

The replicated dynamic equation for the behavioral strategy of the foreman is then:

$$f(y) = dy/dt = y\left(1-y\right)\left(-C_2+K+\left(C_2+F-K-2R\right)x\right) \tag{8}$$

The expected benefits of the workers choosing the "Active participation" or "Passive response" strategy set are V_z and V_{1-z}, respectively, and the average expected benefit is V_3, then we have:

$$\begin{aligned} V_z &= xy(-T-F-\alpha_1P_3) \\ &+x(1-y)(-T+A_2-\alpha_1P_3) \\ &+(1-x)y(-T+A_2-\alpha_1P_3) \\ &+(1-x)(1-y)(-T-\alpha_1P_3) \end{aligned} \tag{9}$$

$$\begin{aligned} V_{1-z} &= xy(-\alpha_2P_3+A_1-F) \\ &+x(1-y)(-\alpha_2P_3+A_1-A_2) \\ &+(1-x)y(-\alpha_2P_3-A_2) \\ &+(1-x)(1-y)(-\alpha_2P_3) \end{aligned} \tag{10}$$

$$V_3 = zV_z + (1-z)V_{1-z} \tag{11}$$

The replication dynamic equation for the worker's behavioral strategy is then:

$$\begin{aligned} f(z) &= dz/dt = z(V_z-V_3) \\ &= z\,(1-z)\left(-\alpha_1P_3+\alpha_2P_3-T-A_1x+2A_2x+2A_2y-4A_2xy\right) \end{aligned} \tag{12}$$

3.4. Equilibrium Analysis

Make the replication dynamic equations to 0, that is Equations 4, 8, 12 to 0. By solving it, we can get eight equilibrium points: $S_1(0,0,0)$, $S_2(0,0,1)$, $S_3(0,1,0)$, $S_4(1,0,0)$, $S_5(1,1,0)$, $S_6(1,0,1)$, $S_7(0,1,1)$, $S_8(1,1,1)$. From Friedman (1991), it is known that the stability of the replica dynamic equation is determined by the eigenvalue of the Jacobi matrix J. The system is asymptotically stable at the equilibrium point if all eigenvalues of the Jacobi matrix are negative real numbers, and unstable at the equilibrium point if the Jacobi matrix has at least one positive real number of eigenvalues. If the eigenvalues of the Jacobi matrix have imaginary roots while the other eigenvalues are real roots, the stability of the system cannot be judged at the equilibrium point. The Jacobi matrix is:

$$J = \begin{pmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{pmatrix} \tag{13}$$

$$J_{11} = \frac{\partial f(x)}{\partial x} = \left(C_{11}-C_{12}\right)\left(-1+x\right)+\left(C_{11}-C_{12}\right)x \tag{14}$$

TABLE 4 | Equilibrium points stability analysis.

Equilibrium points	λ_1	λ_2	λ_3
$S_1(0,0,0)$	$C_{12} < C_{11}$	$K < C_2$	$\alpha_2 P_3 < \alpha_1 P_3 + T$
$S_2(0,0,1)$	$C_{12} < C_{11}$	$K < C_2$	$\alpha_2 P_3 > \alpha_1 P_3 + T$
$S_3(0,1,0)$	$C_{12} < C_{11}$	$K > C_2$	$2A_2 + \alpha_2 P_3 < T + \alpha_1 P_3$
$S_4(1,0,0)$	$C_{12} > C_{11}$	$F < 2R$	$2A_2 + \alpha_2 P_3 < T + \alpha_1 P_3 + A_1$
$S_5(1,1,0)$	$C_{12} > C_{11}$	$F > 2R$	$a_2 P_3 < A_1 + a_1 P_3 + T$
$S_6(1,0,1)$	$C_{12} > C_{11}$	$F < 2R$	$A_1 + \alpha_1 P_3 + T < \alpha_2 P_3 + 2A_2$
$S_7(0,1,1)$	$C_{12} < C_{11}$	$K > C_2$	$\alpha_1 P_3 + T < \alpha_2 P_3 + 2A_2$
$S_8(1,1,1)$	$C_{12} > C_{11}$	$F > 2R$	$A_1 + \alpha_1 P_3 + T < \alpha_2 P_3$

$$J_{12} = \frac{\partial f(x)}{\partial y} = 0 \tag{15}$$

$$J_{13} = \frac{\partial f(x)}{\partial z} = 0 \tag{16}$$

$$J_{21} = \frac{\partial f(y)}{\partial x} = (-C_2 - F + K + 2R)\left(-1 + y\right) y \tag{17}$$

$$J_{22} = \frac{\partial f(y)}{\partial y} = (C_2 - K - (C_2 + F - K - 2R)\, x)\left(-1 + 2y\right) \tag{18}$$

$$J_{23} = \frac{\partial f(y)}{\partial z} = 0 \tag{19}$$

$$J_{31} = \frac{\partial f(z)}{\partial x} = \left(A_1 - 2A_2 + 4A_2 y\right)(-1 + z)\, z \tag{20}$$

$$J_{32} = \frac{\partial f(z)}{\partial y} = (-2A_2 + 4A_2 x)(-1 + z)\, z \tag{21}$$

$$\begin{aligned} J_{33} &= \tfrac{\partial f(z)}{\partial z} \\ &= \left(\alpha_1 P_3 - \alpha_2 P_3 + T + A_1 x - 2A_2 x - 2A_2 y + 4A_2 xy\right)(-1 + 2z) \end{aligned} \tag{22}$$

When the equilibrium point is brought into the Jacobian matrix, it can be found that except J_{11}, J_{22}, and J_{33} are all 0, that is, the Jacobian matrix of S_1-S_8 equilibrium point is diagonal matrix. That is, the values of J_{11}, J_{22}, and J_{33} are the eigenvalues of Jacobian matrix. On this basis, eight equilibrium points are brought into the Jacobian matrix to obtain the conditions required for equilibrium. As shown in **Table 4**.

(1) Whether, safety managers choose Strict supervision or Appeasing supervision because the rewards and punishments incurred due to the strengths and weaknesses of the safety climate are uncertain, what safety managers can determine is their perception of their own inputs. When $C_{11} > C_{12}$, i.e., the safety managers choose the Strict supervision strategy more than the choice of the Appeasing supervision strategy.

(2) For the foreman, the key influential factors affecting his strategy choice were K, C_2, R, and F. The strategy choice of the foreman is more dependent on the handling attitude of the safety managers. When safety managers choose a strict preservation strategy, the foreman weighs the penalty incurred under the managers against the magnitude of prestige within the working group. If the foreman pays more attention to the gains and losses of reputation, then tends to choose the lenient strategy, and vice versa tends to choose tough. When safety managers choose an opposing preservation strategy, the foreman ager weighs the amount of psychological stress imparted by the managers against the additional management paying management costs. If it is difficult for the foreman to assume the pressure of the safety managers, there is a greater tendency to opt for the lenient strategy and vice versa for the tough.

(3) Workers are full participants in the construction process and have more critical influencing factors in their strategy choice, α_1, α_2, P_3, T, A_1, A_2. Once a safety accident occurs, it is a devastating disaster for workers, and the significance of life is paramount. Negative participation of workers in safety construction elevates the probability of safety incidents. In fact, construction engineering makes very much effort to construction safety, and workers' perception of safety incidents is weak. In this case, workers will have a greater perceived gravity of elevating additional safety construction costs. Workers' ethical approval is another large factor that significantly affects workers' behavior, which is specifically expressed in this paper as dissatisfaction A_1 with managers, and psychological compensation A_2 for the foreman. The analysis of influencing factors on worker's strategy selection is more complicated and will be further analyzed in the next section.

In summary, the safety managers' and foremen's perception of loss following an accident is not strong, largely because both parties are less involved in the construction process and are less sensitive to the importance of construction safety. The importance of a safe climate is strongly perceived by workers as direct participants. Excellent safety performance requires a concerted effort from stakeholders, and the most desirable combination of strategies is $S_7(0,1,1)$ and $S_8(1,1,1)$. But it is very difficult for all the participating founders to maintain a high level of safety awareness, the interests of the three parties are staggered, and when safety accidents do not occur, they pay more attention to their gains of interest. Many basic parameters cause changes in the strategies of the parties, and it is necessary to make an approximate prediction of the changes in the strategies caused by the parameters before the numerical simulation. The effects of changes in each parameter on the choice of the tripartite strategy are shown in **Table 5** (effect on the values of x, y, z).

4. SIMULATION ANALYSIS

4.1. Initialization Setting

Foremen and workers use active measures not only to ensure their own safety, but also to preserve their own psychological state of confrontation in the three parties, whereas managers are primarily concerned with punishment for negative effects. There are two main ways to motivate the team to choose a

TABLE 5 | The effects of changes in parameter.

Parameter	Workers (z)	Foremen (y)	Safety managers (x)
$C_{11}\uparrow$	-	-	$\rightarrow 0$
$C_{12}\uparrow$	-	-	$\rightarrow 1$
$F\uparrow C_2\uparrow$	$\rightarrow 0$	$\rightarrow 0$	-
$K\uparrow R\uparrow$	$\rightarrow 1$	$\rightarrow 1$	-
$\alpha_1\uparrow \alpha_2\uparrow$	$\rightarrow 1$	$\rightarrow 1$	$\rightarrow 1$
$P_3\uparrow T\uparrow A_2\uparrow$	$\rightarrow 1$	-	-
$A_1\uparrow$	$\rightarrow 0$	-	$\rightarrow 0$

proactive strategy: first, through managerial pressure to keep the team at least above the safety baseline; and second, by playing a compensatory role (Schaumberg and Flynn, 2021) and raising their awareness to participate proactively. In **Table 5**, it can be seen that the game perceptions of the three groups can be adjusted by the parameters. Since this paper mainly discusses the state and influence of workers, we test how the key parameters affect the ESS of the previously proposed tripartite game model through simulation, and find the evolutionary path by adjusting the constraints, so as to promote the collective behavior to achieve the expected evolutionary stability and obtain excellent safety performance.

The reasonable simulation of three-party data is an important and complex problem, this paper selects a specific project located in Nanchang, China, a research center building. The main building of the research center was designed to have 24 floors and the podium was designed to have 2 floors, with only one tower crane used in each during construction. When the construction of the main building reached 6 floors, the construction of the podium started. As the working surface of the main building is small and adjacent to the podium, the construction teams are prone to conflicts over the use of materials or apparatus when the main building and podium are under construction at the same time, causing safety hazards. It is assumed that during the pouring of the top floor of the podium building, there was a conflict between the reinforcing steel team and the carpentry team due to the right to use the tower crane and the placement of the plates, and that the incident did not result in consequences such as injuries or damage to objects. The value of psychological factors is difficult to define, and this is the key of this paper. Therefore, in the numerical assignment of psychological factors, we choose to carry out long-span and multi-level simulation to ensure generality.

For clearer expression, we limit the setting of parameters to $[0, 10]$. These values only represent the direct relative relationship of parameters and do not represent practical significance. According to the above description, we consider P_3 to be a large value, so we set $P_3 = 7$. Workers' negative responses would make the incidence of safety accidents higher, so $\alpha_2 > \alpha_1$. In order to test the hypothesis and model analysis of evolutionary games, many researchers have used numerical simulation approaches for their studies. Based on the assumptions and analysis of the model in this paper, and in order to facilitate the subsequent numerical simulation of the parameters, we set the initialization of each parameter. The parameters are initially set as follows: $C_{11} = 4, C_{12} = 4, I = 2, F = 3, R = 1.5, K = 3, C_2 = 3.5, P_1 = 2, P_2 = 2, T = 2.8, \alpha_1 = 0.07, \alpha_2 = 0.35, A_1 = 1, A_2 = 1$. In order to facilitate the subsequent numerical simulation calculation, the initialized parameter values are set relatively balanced, and to avoid the influence of subjective factors on the simulation results, we set the initial probability of the tripartite to 0.5.

In order to obtain a more realistic combination of strategies to choose from, the key influencing parameters will be adjusted. The impact of different parameter combinations on evolutionary stability is analyzed by simulating the following scenarios, and the constraints for maintaining effective security are explored.

4.2. The Influence of C_{11}, C_{12}, and F

The strategy selection of safety managers mainly depends on their own perception of management costs under the two strategies (C_{11}, C_{12}). Therefore, in this section, we choose to analyze the influence of changes in C_{11}, C_{12}, and F on three-party strategy selection. Parameter adjustment group, respectively: $\{C_{11} = 3.8, C_{12} = 4, F = 2.8\}$, $\{C_{11} = 4, C_{12} = 3.8, F = 3\}$, $\{C_{11} = 4.2, C_{12} = 3.6, F = 3.2\}$. Set The Times of simulation to 50 and the initial probability of all three parties to 0.5. The simulation results are shown in the **Figure 3**.

It can be seen that safety managers tend to choose Strict supervision strategy more when they choose Appeasing supervision strategy to pay more than Strict supervision. In this case, as the tough penalty measure F declines, workers are more likely to choose to approach safety construction aggressively, as shown in **Figure 3B** as well as **Figure 3C**. And in all three pre-determined situations, the foreman invariably chose to treat workers leniently. The decline in punishment makes the foreman take the punishment instead of the worker in order to maintain his own prestige, and the worker makes a positive response under the influence of the foreman. When safety managers are more inclined to choose Appeasing supervision strategy, foremen do not perceive punishment strongly, and foremen's perception of psychological pressure and management cost paid is a key factor in determining their strategy choice, which deserves further analysis and research.

4.3. The Influence of R, C_2, and A_2

Reputation gain or loss is an important influencing factor for foremen. The time-sensitive nature of construction projects dictates that the construction team and the project manager cannot always maintain a cooperative relationship and will part ways at the end of the construction project or even after the process is completed. However, the construction team will maintain lasting ties, and the foreman, as the top leader of the team, has an important prestige in the minds of the members. Therefore, in this subsection, we choose to analyze the impact of changes in R, C_2, and A_2 on the choice of tripartite strategies simultaneously. The parameter adjustment groups are: $\{R = 1.3, C_2 = 2.5, A_2 = 1\}$,$\{R = 1.6, C_2 = 3.1, A_2 = 1.5\}$,$\{R = 1.9, C_2 = 3.5, A_2 = 2\}$. In order to distinguish the difference between the two attitudes of the safety supervisor, set the first group $C_{11} =$

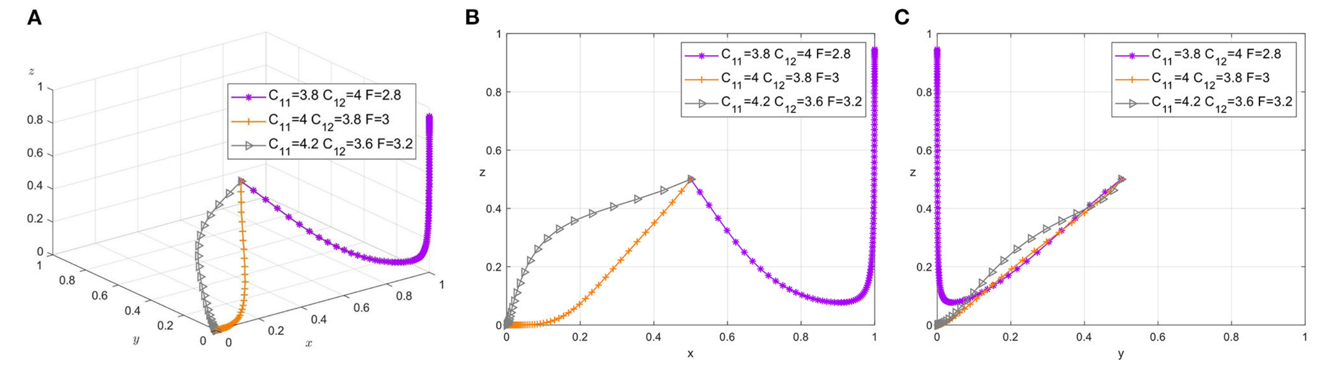

FIGURE 3 | (A) Tripartite strategy evolution. **(B)** Safety managers-workers. **(C)** Foremen-workers.

3.8, $C_{12} = 4$, and the last two groups are $C_{11} = 4$, $C_{12} = 3.8$. Set The Times of simulation to 50 and the initial probability of all three parties to 0.5. The simulation results are shown in the **Figure 4**.

When safety managers choose Appeasing supervision strategy and foremen perceive higher management costs of treating workers strictly, foremen tend to bear the pressure from safety managers alone and treat workers leniently. And with the increase of reputation gain or loss, the faster the rate of foreman tends to be tolerant treatment. At this time, as the workers' psychological compensation to the foreman increases, the workers will tend to choose to actively participate in the safety construction, but the strong punishment from the safety manager will still cause the workers' dissatisfaction, so the workers will turn to negative response after the short tendency to actively participate, as shown in **Figures 4B,C**.

4.4. The Influence of *K*, *T*, and A_1

Workers' behavior is influenced by their own psychological factors, especially the new generation of construction workers, whose psychological factors account for a higher percentage. Meanwhile, construction workers, as direct participants in the construction process, their attitudes toward the safety climate directly determine the safety performance. Therefore, in this subsection, we choose to analyze the effects of changes in K, T, and A_1 on the choice of tripartite strategies simultaneously. The parameter adjustment groups were $\{K = 2.3, T = 1, A_1 = 1\}$, $\{K = 3, T = 2.8, A_1 = 1.5\}$, and $\{K = 4, T = 3.7, A_1 = 2.5\}$. The number of simulations is set to 50, and the initial probabilities of all three parties are set to 0.5. The simulation results are shown in **Figure 5**.

As the foreman bears increased pressure from the safety manager, the foreman gradually tends to choose to treat the worker's management strictly, as shown in **Figure 5A**. With lower pressure from the safety manager, the foreman's choice still tends to be lenient, mainly due to the foreman's valuing of his position in the workgroup. The additional cost of workers' active participation in safety construction increases the tendency for workers to sit on their hands and dissatisfaction with safety managers induces workers to choose negative strategies, as shown in **Figure 5B** as well as **Figure 5C**.

In summary, we analyzed the stability of this evolutionary game model in the above three subsections in terms of the contrasting interests of safety managers, the profit and loss of foremen, and the psychological commitment of workers. In this paper, we set up two strategies for safety managers to manage conflict events, either Strict supervision strategy or Appeasing supervision strategy, foremen and workers need to respond to the way safety managers manage. To achieve the best safety performance, all three participants need to be positive about the safety climate. When the safety manager chooses the Strict supervision strategy and the foreman chooses himself or the worker to bear the punishment, the worker actively participates in the safety construction, i.e., S8(1,1,1), S6(1,0,1); when the safety manager chooses the Appeasing supervision strategy and the foreman actively conveys the management pressure to the worker, the worker actively participates in the safety construction, i.e., S7(0,1,1). However, when these strategy combinations occur, all three participants need to pay high management costs and additional costs, and the three participants will think that the occurrence of safety accidents is a very small probability out of luck, and consider more about their own benefit gain or loss and ignore the perception of project safety performance, as can be seen from the above simulation results, the occurrence probability of S6(1,0,1), S7(0,1,1), S8(1,1,1) strategy combinations do not occur with high probability. The analysis shows that the probability of foreman and worker choosing positive strategies is higher under the appeasing attitude of safety manager. The psychological factors of workers have a greater influence on their behavior, and safety managers can strengthen the safety management performance of the project by enhancing this aspect of management.

5. DISCUSSION

(1) In this paper, we analyze the strategy choices of safety managers, foremen, and workers and their mutual influence through a three-way evolutionary game model. Based on the constructed payoff matrix, we obtained eight stable

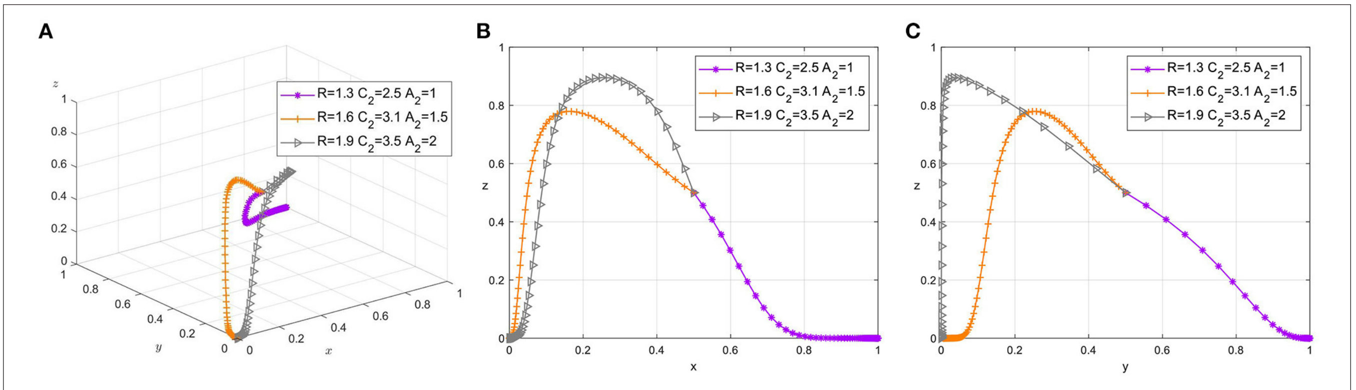

FIGURE 4 | (A) Tripartite strategy evolution. **(B)** Safety managers-workers. **(C)** Foremen-workers.

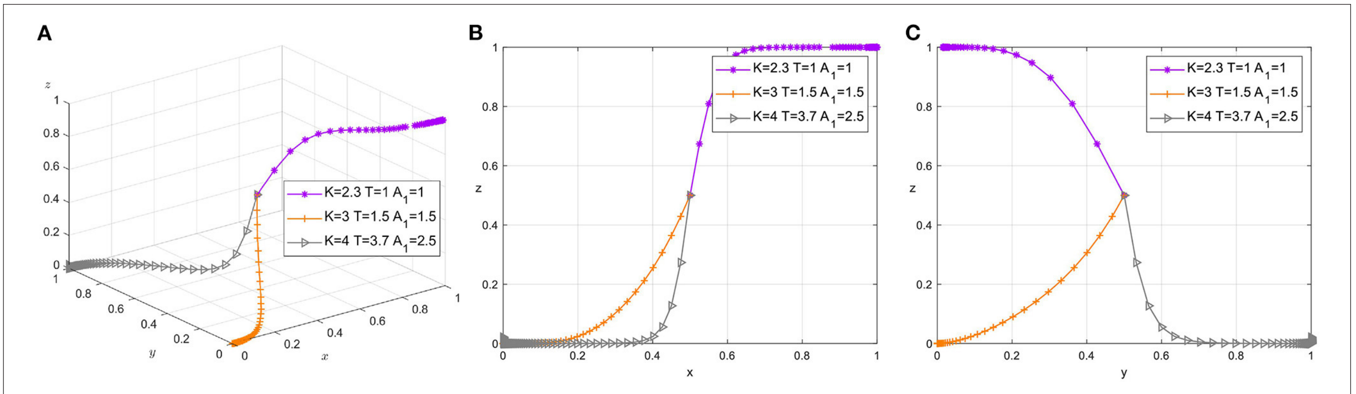

FIGURE 5 | (A) Tripartite strategy evolution. **(B)** Safety managers-workers. **(C)** Foremen-workers.

points: $S_1(0,0,0)$, $S_2(0,0,1)$, $S_3(0,1,0)$, $S_4(1,0,0)$, $S_5(1,1,0)$, $S_6(1,0,1)$, $S_7(0,1,1)$, $S_8(1,1,1)$. In the post-workgroup conflict safety management, we discarded the traditional choice of strict management strategy or regardless strategy for safety managers. We assume that safety managers must be involved in management, but two different management approaches exist, namely strict management and appeasing management. From the point of view of the safety of the whole project, the active participation of all three parties in safety management is the most idealized outcome. In this scenario, the safety manager will choose the strategy with the least perceived effort, and the active participation of foremen and workers in safety management will create a excellent safety climate, and the probability of safety accidents will be greatly reduced. However, this situation is too costly for all three parties and difficult to maintain. In the simulation results it is also found that the situations $S_7(0,1,1)$, $S_8(1,1,1)$ occur less frequently. However, the negative response of workers can lead to a large number of safety hazards, which is very detrimental to the safety performance of the project. In this paper, we mainly consider the influence of workers' psychological factors on their behavior, and promote the safety performance by influencing their psychological state. The following discussion focuses on the influence of the change of each parameter on the strategy choice of the three parties in order to achieve our expected strategy combination.

First, the rewards and penalties received by the safety manager are determined by the probability of a worker-induced safety incident, regardless of which management approach he or she chooses. The safety manager can determine only the management cost paid by each of his own choice of two strategies, C_{11}, C_{12}. The safety manager's strategy choice is mainly determined by these two parameters. However, the safety manager's management style largely influences the strategy choice of foremen and workers. For this reason the safety manager's payoff for both options can only be used as a reference to choose the management style that is more conducive to the active participation of foremen and workers.

Second, reputation is very important to the foreman. The team of workers and foremen together will continue to work for a long time, moving through multiple projects. In general, the leader's ability to control the team is very important, which can maintain a team's excellent performance (Zhu et al., 2021). This makes the foreman prefer to bear the punishment from the safety manager alone to be lenient with the workers within their own team. If the safety manager chooses a soft strategy and does not issue a strong monetary penalty to the work team, instead he applies psychological pressure on the foreman. Psychological pressure is to some extent a higher deterrent for the foreman because the construction project cycle is relatively long, and conflicts between the foreman and the safety manager can easily make the workgroup encounter various obstacles in the process. In this paper, different profit and loss measures of foremen under different attitudes of safety managers are established.

Furthermore, as the main builder of safety climate and the main participant of construction process, workers' behavior directly affects the probability of safety accidents. In order to explore the influence of workers' psychological factors on safety construction in an all-round way, we selected the indicators of dissatisfaction with safety managers and identification with foremen influenced by workers' moral identity, A_1, A_2. Through simulation we can find that the joint management of safety managers and foremen has a greater influence on workers. Workers' dissatisfaction with safety managers leads to their negative emotions, while the foreman's tolerant treatment leads to workers' psychological compensation and active participation in safety construction. At the same time, the direct victim of safety accidents is also the worker, and the perceived level of safety loss is also a significant influence on the workers' behavioral choices.

(2) In terms of safety in the construction industry, an excellent safety culture and safety climate can enable projects to achieve a high level of safety performance, and there is a constant confrontation between managers and construction teams in the construction of safety culture and climate (Al-Bayati, 2021). However, confrontation brings only hindrances to the operation of the project; it is the efficient collaboration of all parties involved that makes the project run smoothly. As a result, many academics have concentrated on how to mediate between project partners in order to improve the project's safety climate. Li et al. (2017) assessed the safety climate from three perspectives: workers, safety environment, and safety management, and proposed that the recognition of workers and the pressure given by managers have an impact on the safety climate indicators. Umar and Egbu (2018) further noted that managers' commitment, employees' empowerment, and workers' safety engagement can all have a major impact on the safety climate of construction projects. Personality requirements for construction workers have increased in the current era. Tough management tactics cause people to rebel, and emotionally-driven behaviors yield unfavorable outcomes, lowering managers' prestige and decreasing management effectiveness. In short, it is not advisable to use stereotypical management methods if managers want to achieve efficient management effectiveness as well as excellent safety performance, especially after a conflict incident, where the handling of the incident is as important as the emotional reassurance of construction workers.

(3) The construction industry is distinguished by a huge number of workers and a small number of supervisors. For incidents that do not result in serious consequences, managers are to some degree in a weaker position, they choose to avoid such events and thus reduce the potential for worker hostility or what other managers perceive as hidden losses. Even minor safety problems, have the potential to result in casualties. Owners and investors should invest more in safety, reduce managers' subjective awareness of risk ratings, and minimize ignorance of safety threats for a range of personal reasons in order to reduce safety risks.

To this end, we make the following suggestions: (1) Construction units should adopt more favorable rewards and more severe punishments according to the merits of safety managers' management performance in order to motivate safety managers to deal with safety hazards more seriously and responsibly. (2) Construction units should pay more attention to the importance of foremen in safety education and improve the role of foremen as intermediaries between safety managers and workers. (3) Construction units should pay attention to the impact of construction workers' mental health on safety behavior, and promptly deal with incidents that occur among workers to avoid very hidden and huge safety hazards caused by psychological problems.

6. CONCLUSION

In this paper, a tripartite evolutionary game model of post-conflict handling in a workgroup is developed to explore the effects of the level of moral identity of workers and the role of the leader of the workgroup, and the two attitudes of the manager (Strict supervision, Appeasing supervision) on the tripartite strategy, and providing some suggestions and references for finding the best way to handle the situation. During processing, workers' state adjustment is an important factor affecting project safety performance, and the use of evolutionary game theory allows for both targeted study of changes in important parameters, as well as intuitive exploration of the effects on tripartite behavior while parameters are changing.

The new generation of construction workers is self-aware and rebellious, and the attitude of managers toward workers affects their initial attitude and key parameters. Therefore, in the management measures, the past participation results and membership composition of the incoming team should be fully considered, instead of all tough penalties. In addition, it is important to improve the education of managers and construction teams, which is of great significance to maintain the safety performance of the project.

It is impractical to fully understand the behavioral orientation of managers and teams through a game. In this paper, we do not intend to analyze which strategy can achieve the best safety results through a game; instead, we introduce key variables under the highest safety performance strategy combinations and look for optimization measures to enhance management efficiency.

In the future, we will explore how more factors affect the safety performance and management efficiency of projects, especially the prevention of small incidents that may lead to serious accidents, such as conflicts between project hierarchical relationships. Future work will focus on using algorithms to analyze the cooperation and confrontation of project populations and to compare more accurately and clearly the differences between the proposed model and other models.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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