

## **Research on the optimal allocation of safety investment in construction enterprises**

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**Abstract** From the perspective of control function, the index system of safety investment intensity of construction enterprises is established. Taking preventive security investment as the research object, the ranking of safety investment intensity is determined according to the significance model of preventive security investment, and the optimization model of safety investment intensity distribution is determined based on accident loss safety investment, providing effective guarantee for construction enterprises to reasonably allocate security investment intensity and improve safety production efficiency.

**Key Words** Construction enterprise; Safety investment; Importance degree; Optimize

### **1 Introduction**

Construction industry is a labor-intensive industry, and engineering construction is a complex, dynamic process affected by many factors, which is a high-risk job. However, the safety awareness of construction enterprises is weak and the investment in safety is insufficient, which leads to frequent safety accidents, causing a large number of economic losses and casualties. The reputation of enterprises will also be affected to a certain extent. In recent years, increasing safety investment has become an important means for construction enterprises to improve safety production quality and efficiency. However, simply increasing the safety investment intensity doesn't have an obvious effect on the safety investment efficiency. In-depth discussion on the optimization of the allocation of safety investment intensity of construction enterprises is of practical significance to avoid the occurrence of potential hazards in the construction process, reduce casualties and economic losses, and improve the safety investment efficiency <sup>[1]</sup>.

Foreign researches on safety investments of construction enterprises are earlier than those in China. In the 1950s, Simonds et al. proposed the concept of safety investments <sup>[2]</sup>. Following the criterion of process and quality management and ignoring safety management, Levitt construction enterprise suffered accidents and losses due to insufficient safety investments <sup>[3]</sup>. Scott Farrow points out that there is a close relationship between safety investments and safety benefits <sup>[4]</sup>. American scholar Jimmie Hinze has studied eight safety investment issues like safety education, accident investigation and system establishment <sup>[5]</sup>. K.S. Son et al. proposed the optimal proportion of safety investment with Korean construction industries as the research objects <sup>[6]</sup>. Jimmie w. Hinze believes that safety investments not only covers the cost of safety management of construction enterprises, but also the direct and indirect economic losses caused by safety accidents <sup>[7]</sup>. Herbert Heinrich's research suggests that the ratio of direct loss to indirect loss is 1:4 <sup>[8]</sup>. Foreign researches on the safety investment of construction enterprises are mainly carried out gradually from the introduction of concepts study of the importance of safety investments. Problems of safety investments in construction projects are summarized, and optimization studies are carried out by combining safety investments and safety benefits.

With the deepening study on the safety investment of construction enterprises in foreign countries, China began to pay attention to the importance of safety management in construction projects in the 1980s. Ye GUI et al. determined the fundamentally influential factors of safety investment behavior decision of construction industry through ISM model <sup>[9]</sup>. Through investigation and research, Qiang Maoshan et al. concluded that the safety investment of construction projects can be divided into four major parts: civilized construction, safety facilities, labor protection and safety education <sup>[10]</sup>. Zhang Shuangming determined the optimal investment point of safety investment by studying the relationship between safety investment and safety benefit of construction enterprises <sup>[11]</sup>. Lu Ning et al. put forward the correlation degree model of safety investment, and measured the contribution of various safety investment indicators to reduce actual economic losses, and the dynamic optimization of safety investment ratio <sup>[12]</sup> · <sup>[13]</sup>. At the present stage, the research on the safety investment of construction enterprises is mainly aimed at the relation between safety benefits and the evaluation method of safety investment. There are few studies on establishing the safety investment index

system from the perspective of safety accident control, reducing the occurrence of safety accidents and optimizing the safety investment intensity.

## 2 Safety investment index system

Safety investment of construction enterprises refers to all economic activities related to safe production that can effectively guarantee the working environment and safety of staff, prevent occurrence of safety accidents, and reduce economic loss when the construction project is successfully implemented. The benefit of safety investment is to minimize the negative impact of safety accidents in the process of implementing safety investment. It runs through the whole process of construction project construction and has the function of "impairment reduction" and "value-added capacity", which is both economic and social <sup>[13]</sup>.

The safety investment of construction enterprises is potential, indirect and lagging. From the perspective of control function, it mainly includes two aspects: one is proactive investment mainly in prevention, which belongs to prior investment, including safety management investment, environmental protection investment, personnel quality investment, technical equipment investment and emergency insurance investment; the other is passive investment which mainly focused on the handling of accident losses and belongs to the in-event and post-event investment, including the investment in accident rescue and post-event treatment <sup>[1]</sup>. Construction enterprise's safe investment index system is shown in table 1. The reasonable allocation of preventive safety investment can effectively reduce the accident loss investment, that is, reduce the occurrence rate of safety accident or reduce the actual economic loss and casualties caused by it, so as to improve the safety investment benefit. The accident loss investment is in the form of the actual economic loss caused by the safety accident of the construction enterprise, which consists of two parts: direct economic loss and indirect economic loss. Therefore, in the actual production of construction enterprises, the main way to control the safety investment is to take the preventive safety investment as the main method, and to restrain the accident loss investment, which can improve the safety production efficiency.

**Table 1 safety investment index system of construction enterprises**

Target	Property	Index classification	Index name	Notes
Safety investment of construction enterprises	Preventive safety investment	Safety Management investment	Daily management	Relevant investments required for professional safety personnel, site safety management and daily office work.
			systematic management	To improve and standardize the safety of the enterprise and the construction site
		Environmental investments	Labor protection	To protect the safety and health of workers on site
			Civilized construction	For safe and civilized construction of construction site, office area and living area
		Investment in personnel quality	Health	To improve the quality of production environment and on-site workers and staff health
			Education and training	Education for safe production to improve the safety knowledge and awareness of workers and staff on site
		Investment in technical equipment	Construction technology	To avoid the occurrence of safety accidents, the prevention and control of common accidents related technology investment
			Mechanical equipment	To ensure the safe use of machinery and equipment used in construction
		Emergency insurance investment	Emergency rescue	To ensure the effective control of emergencies, the prevention and control of dangerous sources

Table 1, cont.

			Security insurance	To prevent the impact of the workers in the field with the serious consequences of occupational hazard and accidents
Lost safety investments	Post-processing investment		Compensation for work-related injuries	Additional compensatory investment to the victim's work injury after the accident
			Accident handling	All after-works required after the accident
	Rescue control investment		Accident control	All investments required to avoid further aggravation when an accident occurs
			Accident rescue	All rescue investment needed for the accident

### 3. Model of importance of preventive security investment

The ultimate goal of safety investment of construction enterprises is to maximize the benefit of safety investment with reasonable intensity distribution, and to minimize the economic loss. There is a direct correlation between each precautionary safety investment and the safety investment benefit. The greater the correlation between the two, the greater the contribution of the precautionary safety investment to the safety investment benefit and the greater its importance. Therefore, it is necessary to rank the importance of preventive security investment <sup>[14]</sup>.

#### 3.1 Determination of index sequence

According to heinrich's statistics <sup>[7]</sup>, the ratio of actual economic loss and direct economic loss in accidents of construction enterprises is 5:1, and safety investment benefit is selected as the parent sequence, namely the reference sequence, as shown in equation (1) and (2).

$$Y(k) = \{5y^{\max}(k) - 5y(k) | k = 1, 2, K, n\} \quad (1)$$

$$Y = \{Y(k) | k = 1, 2, K, n\} \quad (2)$$

In the equation,  $y(k)$  is direct economic loss for construction enterprises in the first year of a safety accident, ten thousand yuan;  $y^{\max}(k)$  is the maximum direct economic loss of safety accidents in the year, ten thousand yuan;  $Y(k)$  is the safety investment benefit of year  $k$ , ten thousand yuan.

The sub-sequence, i.e., comparison sequence, is established according to the index system of preventive safety investment of construction enterprises, as shown in equation (3).

$$X_i = \{X_i(k) | k = 1, 2, K, n\} \quad (3)$$

In the equation,  $X_i(k)$  Represents security investments for year  $i$  of item  $k$ ;  $i = 1, 2, K, 10$ .

#### 3.2 Data sources and processing

According to the index connotation of safety investment index system of construction enterprises, the amount of preventive safety investment and the direct loss of accidents are determined through the financial accounting details of construction enterprises.

Considering the difference of sequence values, the extreme value method was used to conduct pure

quantization treatment for reference sequence and comparison sequence, and the pure quantization sequence of safety investment benefit  $Y_i^*$  and the pure quantization sequence of preventive security investment  $X_i^*$  were obtained respectively, as shown in equation (4) and (5).

$$Y^* = \left\{ \frac{Y(k) - Y^{\min}(k)}{Y^{\max}(k) - Y^{\min}(k)} \mid k = 1, 2, \dots, K, n \right\} \quad (4)$$

$$X_i^* = \left\{ \frac{X_i(k) - X_i^{\min}(k)}{X_i^{\max}(k) - X_i^{\min}(k)} \mid k = 1, 2, \dots, K, n \right\} \quad (5)$$

Where  $Y^{\max}(k)$  is the maximum safety investment benefit in  $k$  year,  $Y^{\min}(k)$  is the minimum safety investment benefit in  $k$  year, ten thousand yuan;  $X_i^{\max}(k)$  is the maximum amount of preventive security investment in year  $k$  of item  $i$ , and  $X_i^{\min}(k)$  is the minimum amount of preventive security investment in year  $k$  of item  $i$ , million yuan.

### 3.3 Correlation coefficient between preventive safety investment and safety investment benefit

According to equations (4) and (5), the maximum difference  $\Delta_i^{\max}$  and minimum difference  $\Delta_i^{\min}$  between the benefit of security investment and preventive security investment can be obtained, as shown in equations (6) and (7).

$$\Delta_i^{\max} = \max_i \left( \max_k |Y^*(k) - X_i^*(k)| \right) \quad (6)$$

$$\Delta_i^{\min} = \min_i \left( \min_k |Y^*(k) - X_i^*(k)| \right) \quad (7)$$

According to equations (6) and (7), the correlation coefficient  $\xi_i(k)$  of item  $i$ 's precautionary safety investment index and safety investment benefit can be obtained, as shown in equation (8).

$$\xi_i(k) = \frac{\Delta_i^{\min} + \alpha \Delta_i^{\max}}{|Y^*(k) - X_i^*(k)| + \alpha \Delta_i^{\max}} \quad (8)$$

Where:  $\alpha$  is the resolution coefficient, and the value range is  $(0,1]$ , where the time resolution  $\alpha = 0.5$  effect is the best, so 0.5 is selected as the resolution coefficient.

### 3.4 Ranking of the importance of each preventive security investment

As the obtained correlation coefficient is the dispersed value within the year  $k$  of each index, it is not easy to compare with each other, so it is necessary to calculate the contribution degree of each index to the safety investment benefit. According to the effect efficiency of different indicators on the actual economic loss of accidents, the ratio of each indicator to the safety investment benefit, namely the safety investment efficiency, can be determined, and the  $k$  annual average is taken as the weight  $\omega_i(k)$  of a single index, as shown in equation (9). According to equations (8) and (9), the significance  $\gamma_i$  of each indicator to the benefit of safe investment is obtained, as shown in equation (10).

$$\omega_i(k) = \frac{1}{n} \sum_{k=1}^n \frac{X_i(k)}{Y(k)} \quad (9)$$

$$\gamma_i = \sum_{k=1}^n \omega_i(k) \xi_i(k) \quad (10)$$

According to the importance  $\gamma_i$  of safety investment benefit, the preventive security investment is ranked, and the greater the value, the greater the investment intensity of this index.

#### 4 Safety investment optimization model

According to the classification of safety investment of construction enterprises and the impact of various preventive safety investment on the accident loss safety investment, the function relationship between various preventive indicators and the actual economic loss of accidents is expressed in the form of cobb-douglas production function, and the safety investment optimization model <sup>[15]</sup> · <sup>[16]</sup> is established, as shown in equation (11).

$$Z = \sum_{i=1}^{10} X_i + y = \sum_{i=1}^{10} X_i + f(X_1, X_2, K, X_{10}) = \sum_{i=1}^{10} X_i + M X_1^{\beta_1} X_2^{\beta_2} L X_{10}^{\beta_{10}} \quad (11)$$

Where:  $Z$  represents the safety investment of construction enterprises, ten thousand yuan;  $y$  is the accidental investment, ten thousand yuan;  $M$  is the technical progress index, and  $\beta_i (i=1, 2, K, 10)$  is the output elasticity index corresponding to each preventive security investment index.

According to the importance of preventive safety investment and its relationship and characteristics with accident loss investment, the safety investment model of construction enterprises needs to meet the following conditions:

(1)  $\lim_{X_i \rightarrow 0} = \infty$ , all kinds of preventive safety investment play a vital role in the control of safety accidents of construction enterprises. Any index exists and cannot be ignored.

(2) The preventive safety investment of construction enterprises is ranked according to its importance;

(3)  $\frac{\partial f}{\partial X_i} < 0 (i=1, 2, K, 10)$ , under the condition that other preventive safety investment remains unchanged,

a certain preventive index can increase the investment intensity to reduce the accident loss safety investment of construction enterprises;

(4) the accident loss safety investment shall not exceed the limit value  $C$ , which is the actual economic loss of the accident caused by or acceptable to the construction enterprise.

To sum up, the goal of safety investment allocation optimization of construction enterprises is to minimize the actual economic loss of safety accidents within the minimum investment intensity. In combination with the idea of target planning, the safety investment optimization model can be established as follows:

$$\begin{aligned} \min Z &= \sum_{i=1}^{10} X_i + y \\ \text{s.t.} &\begin{cases} Y \leq C \\ X_a \geq X_b \geq L \geq X_j \geq 0 \end{cases} \end{aligned} \quad (12)$$

Where:  $X_a, X_b, L, X_j$  are preventive safety investment indexes sorted by importance.

#### 5 Conclusion

(1) According to the characteristics of safety accidents in construction enterprises, the safety investment index system of construction enterprises is established from the perspectives of prevention and accident treatment. The preventive safety investment includes 5 categories and 10 indicators, and the rational safety investment in accident handling includes 2 types and 4 indicators.

(2) The safety investment of construction enterprises is mainly preventive security investment. Considering the contingency and inevitability of safety accident and its potential and indirect influence on safety accident, by virtue of its contribution to safety investment benefit, the significance model of preventive security investment is obtained and the indexes of preventive security investment are ranked.

(3) Based on the safety investment indicator system of construction enterprises and the importance model of preventive safety investment, and combining the characteristics of preventive and accident safety investment, an optimization model of safety investment intensity distribution was established to reasonably determine the safety investment intensity of construction enterprises.

Safety management is the key in the integrated management of construction projects. Reasonable allocation and optimization of safety investment by construction enterprises can avoid blind investment, improve safety production efficiency, reduce accidents and casualties, and ensure the smooth completion of projects.

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