Safety Performance Evaluation System: A Brief Review

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Abstract. Safety is the lifeline of enterprises and a line that cannot be crossed. In recent years, despite the strengthened supervision, inspection, and punishment efforts in safety management by various enterprises, accidents resulting in injuries and casualties still occur from time to time. Therefore, it is necessary to establish a safety performance evaluation system that can not only ensure training enthusiasm but also demonstrate risk control capabilities, to provide a more objective evaluation of safety management work. This paper summarizes the types of general safety performance evaluation index systems, organizes methods for determining event risk factors, reviews safety performance evaluation methods, which are significant in constructing a system that objectively reflects the level of enterprise safety management, scientifically conveys safety management pressure, and enhances the level of productivity in enterprises.

Keywords: Safety assessment, Risk assessment, Performance evaluation

1 INTRODUCTION

Safety performance can effectively measure the level of enterprise safety management within a certain period, which plays a crucial role in enhancing enterprise productivity. Nowadays, grassroots managers in enterprises generally receive higher education and their ideological concepts closely follow the trend of informatization. Therefore, there is an urgent need for a scientific, advanced, and human-centered safety performance evaluation system to actively promote the routine and standardized construction of enterprise safety management.

In recent years, the aviation industry[1], coal mining industry[2], and construction industry[3] have experimented with safety performance assessment systems to evaluate safety management work within enterprises. These assessment systems utilize mathematical evaluation models to comprehensively assess the safety operation status of enterprises and accurately assess the safety conditions at different stages as well as predict future overall operational trends. This provides decision-makers with scientific and reliable theoretical basis for developing measures and implementing effective management. It is a widely applied and relatively scientific method in modern safety management. However, due to different strategic objectives, operational methods, and the inherent ambiguity and non-quantitative characteristics of safety issues within different units, as well as the diverse sources of safety threats, it may be challenging to conduct

R. Magdalena et al. (eds.), *Proceedings of the 2024 9th International Conference on Social Sciences and Economic Development (ICSSED 2024)*, Advances in Economics, Business and Management Research 289,
https://doi.org/10.2991/978-94-6463-459-4_96

precise quantitative calculations when using modern mathematical models for systematic evaluations. This can impact the smooth implementation of safety assessments and the accuracy and effectiveness of evaluation results.

Therefore, focusing on the objective requirements for enhancing the new quality of productivity in the new era, it is urgently necessary to explore and establish a comprehensive safety performance evaluation system that considers the severity of training subjects in crisis situations and can be quantified. This system should enable the quantitative calculation of safety elements in the evaluation targets, thereby obtaining objective, reliable, and comparable results. The construction of this system is of significant practical significance for reinforcing the concept of practical training, in-novating practical training modes, improving practical training mechanisms, and enhancing practical training practices to strengthen combat readiness.

2 SAFETY PERFORMANCE EVALUATION INDEX SYSTEM

Safety performance describes a comprehensive indicator of various aspects of safety within an enterprise, and this comprehensive indicator is influenced by various factors. Therefore, selecting appropriate indicators to characterize safety performance is crucial for evaluation. When designing or selecting safety performance indicators, many factors need to be considered. The principles proposed for setting safety performance indicators have been widely accepted: ① Evaluation projects should not be limited to injury accidents alone; to avoid deviations in scope and duration, the evaluation period should not be too short. ② Evaluation projects should be closely related to all production operations being carried out, particularly in aspects related to operational capabilities, in order to mitigate severe consequences caused by harms to the system. ③ The quantified values obtained from evaluation should be replicable and applicable by anyone knowledgeable in this evaluation technique[4]. Safety performance evaluation has mainly relied on accident data, injuries, and other related information. Common safety performance evaluation indicators are as follows[5]:

2.1 Accident Rate (AR) or Incident Rate (IR)

The accident rate (AR) or incident rate (IR) can be calculated using various methods such as the number of accident hours lost or event hours lost, incident rate of all hours lost, serious rate or day loss rate of accidents or events, or the number of recordable incidents of non-day lost injuries or illnesses. Although some studies suggest that using accident rates or incident rates for safety performance evaluation is superior to other indicators, evaluating safety performance using accident rate indicators may not facilitate effective performance comparisons. This is because the absence of accidents in one unit does not necessarily indicate better safety management practices compared to another unit that has experienced safety incidents.

2.2 Experience Modification Rating (EMR)

Using the experience modification rating (EMR) to assess a company's safety performance is a common practice. It is an index that has long been used to measure a company's comprehensive safety record. The purpose of EMR is to establish a closer connection between occupational injury insurance costs and employer losses, and better predict future accident losses based on past occurrences. Employers whose accident claim amounts exceed the average level pay additional costs when contributing to occupational injury insurance, while those below the average level enjoy discounts. This motivates employers to improve their safety records by reducing occupational injury insurance costs for safe production employers and in-creasing costs for those with unsafe production practices. Using accident data alone to measure safety performance is inappropriate. It may lead to biases such as insensitivity, low material credibility, retrospective analysis, and neglect of objective risk probabilities, making it difficult to truly evaluate enterprise safety performance. Furthermore, such approaches make limited contributions to accident prevention, particularly when considering the different nature of enterprises and varying hazard situations they face. Therefore, when selecting performance evaluation indicators, some scholars and institutions consider indicators that reflect the operational status of enterprise safety production systems in addition to relevant indicators. The British Standard BS8800 divides safety performance evaluation into proactive and reactive indicators.

3 EVENT RISK COEFFICIENT DETERMINATION

The basis for quantifying indicators is a scientific argumentation, careful calculation, and extensive solicitation of opinions from various stakeholders. Ensuring the scientific validity of indicators is the fundamental prerequisite for establishing indicator assessment standards. Indicators can be categorized into qualitative and quantitative indicators, each with different content and focus points in assessment. Specifically, quantitative indicators focus on evaluating outcomes, while qualitative indicators focus on evaluating processes. The quantitative analysis methods used in this article are as follows[6]:

3.1 Qualitative Indicators

For the analysis of qualitative indicators, a segmented scoring method is utilized. The segmented scoring method involves assigning values to different levels of task achievements or behavioral performance within intervals. It is a commonly used and effective method for measuring qualitative indicators and is one of the most straightforward and practical approaches. Qualitative indicators such as the importance and support of safety by leadership, the completeness and rationality of enterprise safety objectives and policies, the adequacy of organizational structure, and employee satisfaction with the safety conditions of the company can be described using graded language and assigned different interval values for different levels to obtain assessment result scores.

3.2 Quantitative Indicators

Quantitative indicators are defined and measured accurately in numerical terms. There are various quantitative methods based on the nature of the indicators. Common methods include:

- Statistical result quantification method: This method directly provides digitized statistical results based on the condition after task completion, such as frequency, profit rate, etc.
- Target achievement quantification method: This method compares the results after task completion with the expected targets beforehand to derive measurable differences between target and actual results, such as completion rate, target realization rate, measure implementation rate, etc.
- Frequency quantification method: This method calculates results based on the frequency of task completion or behavioral performance, including completion frequency, occurrence frequency of failures, frequency of human errors, etc.

For the quantification of accident indicators, specific determinations need to be made based on the actual circumstances of different units.

3.3 Risk Matrix Table Method

The risk matrix table method measures the size of risk based on the multi-plication of the likelihood of an event occurring and the potential loss it may cause. The formula for calculating risk value is represented as follows: $D = p \times C$, Where,D represents the magnitude of the risk value,p denotes the likelihood of the event occurring, which can be determined by referring to a standard table based on different accident frequency values,C signifies the potential loss resulting from the event, which can be determined by referring to a standard table assigning values to different levels of accident losses.

4 EVALUATION METHODS OF SAFETY PERFORMANCE

At the beginning of safety performance research, various evaluation methods have been developed and adopted, including Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation, Management Oversight and Risk Tree (MORT) method, Data Envelopment Analysis (DEA), Structural Equation Model (SEM), and Artificial Neural Network (ANN) evaluation method, among others. Although these methods have different theoretical foundations, each method has its own advantages and disadvantages. Choosing the appropriate mathematical method for evaluation not only helps in data collection and analysis of indicators but also makes the evaluation process more practical and straightforward. Below, we analyze different evaluation methods through relevant applications.

4.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multicriteria decision making method that combines qualitative and quantitative analysis. Proposed by the prominent American operations researcher T.L. Saaty in the 1970s, AHP breaks down complex problems into goal levels, criterion levels, solution levels, etc., and determines the relative importance of factors through judgment matrices to obtain a total ranking of factor importance. AHP is a tool that simulates human thinking processes and provides a concise and practical decision making method for analyzing complex problems. It can conduct both quantitative and qualitative analysis, and the evaluation results require consistency checks, ensuring high reliability.

4.2 Fuzzy Comprehensive Evaluation

During the evaluation process, people often encounter indicators with fuzzy characteristics or relationships between evaluation levels that are fuzzy. Fuzzy mathematical evaluation methods utilize basic fuzzy mathematical principles and analysis methods to establish a mathematical risk assessment matrix for evaluating objects with fuzziness and uncertainty. This method is widely applied in safety assessments. The approach focuses on factors and comments that are fuzzy and cannot be described accurately using precise mathematical language. The analysis process involves determining the factor set and evaluation set of the object being evaluated, then establishing the weight and membership degree vector for each factor, obtaining a fuzzy evaluation matrix, and finally conducting fuzzy operations and normalization with the factor weight vector to obtain the overall evaluation result.

4.3 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a statistical analysis method developed by renowned operations researchers A. Charnes and W. Cooper, based on the concept of "relative efficiency." It evaluates the relative effectiveness or efficiency of similar unit departments based on multiple input and output indicators. Through comprehensive analysis of input and output data, DEA calculates quantitative indicators of the overall efficiency of each decision unit, identifies efficient decision units, analyzes the reasons for non-DEA efficiency in each decision unit, and provides essential management decision information for decision-makers.

4.4 Structural Equation Model (SEM)

The Structural Equation Model (SEM) analyzes the relationships between variables based on the covariance matrix (or correlation matrix) of variables. It can be divided into measurement equations and structural equations, where measurement equations describe how latent variables are measured or conceptualized by preceding indicators, and structural models, also known as latent variable models or causal models, measure the relation-ships between latent variables. This method can address the limitations of traditional methods in handling relationships with multiple causes, multiple results, and variables that cannot be observed directly. While SEM requires strict compliance with regulations during use, has high requirements for scale design, and unclear causal relationships. The SEM model was introduced into the evaluation system, constructing a Structural Equation Model for safety performance evaluation, and deducing the ranking of the importance of different safety performance influencing factors.

4.5 Artificial Neural Network (ANN)

Artificial Neural Network (ANN) evaluation is an intelligent algorithm that mimics the working principles of the human brain's neurons. It stores data or knowledge provided in a large number of neurons or the entire system, establishes relationships between input and output through learning and training on samples to uncover the inherent connections between them, providing a solution to problems using this intelligent algorithm. The artificial neural network imitates the functional principles of biological neural networks, establishing neurons based on input information, developing corresponding non-linear models through learning rules or self-organizing processes, continuously correcting outputs to narrow the gap between output results and actual values, and evaluating unknown samples using stored non-linear network relationships, like the associative function of the human brain.

5 CONCLUSIONS

The safety performance evaluation system is essential for measuring safety management and enhancing productivity. It involves selecting appropriate indicators like Accident Rate, Experience Modification Rating, and others to assess safety comprehensively. Risk coefficients are determined using quantitative and qualitative indicators, such as the risk matrix table method, which categorizes risks based on event likelihood and potential losses. Various evaluation methods like Analytic Hierarchy Process, Fuzzy Comprehensive Evaluation, Data Envelopment Analysis, Structural Equation Model, and Artificial Neural Network offer unique strengths for analyzing safety performance. Choosing the right method depends on specific evaluation needs. In conclusion, leveraging a combination of indicators and evaluation methods can lead to a robust safety performance evaluation system, benefiting decision-makers in implementing effective safety measures and improving safety management practices.

ACKNOWLEDGMENT

This work was supported by the National University of Defense Technology Re-search Program. The project is "Construction of Safety Performance Evaluation System Considering the Risk Level of Training Subjects" under project number js20-05.

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