Type of Contribution:
Editorial
Research Paper
Review Paper
Case Study

ENERGY: JURNAL ILMIAH ILMU-ILMU TEKNIK
Vol. 16, No. 2 (2026) pp 348-360
DOI: 10.51747/energy.v16i2.pp348-360
E-ISSN: 2962-2565

This article contributes to:

SUSTAINABLE DEVELOPMENT GOALS

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Determinants of Behavior-Based Safety Performance in Coal-Fired Power Plants Using Structural Equation Modeling

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Abstract

Occupational safety is a critical issue in coal-fired power generation industries due to the high-risk nature of operational and maintenance activities. Preliminary observations at a power generation company identified several unsafe behaviors, including non-compliance with work permits, improper use of personal protective equipment (PPE), violations of standard operating procedures, unsafe workplace arrangements, and inappropriate behavior during hazardous activities. This study aimed to identify factors influencing Behavior-Based Safety (BBS) and determine the most significant predictors of employees' safety behavior. A quantitative cross-sectional approach was applied, with data analyzed using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM). The results indicated that employee attitude ($p = 0.004$) and the implementation of occupational health and safety (OHS) regulations ($p = 0.003$) had significant positive effects on safety behavior ($p < 0.05$). Meanwhile, safety knowledge, work motivation, PPE availability, OHS training, reward systems, and punishment mechanisms showed no significant influence on BBS ($p > 0.05$). These findings highlight that strengthening safety attitudes and organizational OHS implementation plays a more dominant role in improving employee safety behavior compared to knowledge-based and incentive-based interventions. The SEM model developed in this study can support safety management strategies and contribute to establishing a sustainable zero-accident culture in high-risk industries.

Keywords: Behavior-Based Safety; Safety Behavior; Structural Equation Modeling; Occupational Health and Safety; Coal-Fired Power Plant.

Article Info

Submitted: 2026-06-10
Revised: 2026-07-11
Accepted: 2026-07-13
Published: 2026-07-15

Publisher

Universitas Panca Marga

1. Introduction

Occupational accidents remain a major concern in industrial organizations because they may cause injuries, occupational diseases, property losses, and reduced operational performance. In high-risk industries, occupational safety management emphasizes hazard identification, risk control, and preventive actions to protect workers from workplace hazards. Indonesian Law No. 1 of 1970 concerning Occupational Safety states that employers are responsible for ensuring workplace safety and protecting employees from occupational risks [1]. Despite continuous improvements in safety management systems, occupational accidents remain closely associated with unsafe behavior, which has been identified as one of the dominant contributors to workplace incidents [2], [3]. Therefore, understanding the factors influencing employee safety behavior is essential for developing effective accident prevention strategies.

One approach that has received considerable attention in occupational safety management is Behavior-Based Safety (BBS). BBS focuses on identifying, observing, and modifying unsafe behaviors through employee involvement, behavioral feedback, and organizational commitment to safety improvement [4], [5]. The concept emphasizes that sustainable safety performance cannot rely solely on engineering controls or administrative procedures but also requires active participation from employees in maintaining safe work practices [6], [7]. Previous studies have demonstrated that BBS implementation can improve safety behavior, reduce unsafe actions, and support accident prevention efforts in various industrial environments [8], [9].

Although previous studies have extensively discussed the implementation and effectiveness of BBS programs, many investigations have focused primarily on intervention outcomes, safety performance improvement, and reduction of unsafe behavior [8], [9]. Other studies have examined individual factors associated with unsafe actions and safety behavior, including safety knowledge, safety attitudes, and employee characteristics in manufacturing and service industries [2], [10], [11], [12]. However, safety behavior is a complex phenomenon influenced by interactions between individual, organizational, and environmental factors. Therefore, examining these determinants simultaneously within an integrated structural framework remains necessary, particularly in high-risk industries.

Coal-fired power plants represent one of the industrial sectors with significant occupational risks due to continuous production activities, complex operational systems, and exposure to multiple hazards. Workers in power generation facilities are frequently involved in high-risk activities such as high-voltage electrical work, hot work, confined space entry, working at height, lifting operations, and chemical handling. Although occupational health and safety (OHS) programs have been implemented, unsafe behaviors may still occur during daily operations, including failure to comply with permit-to-work procedures, improper use of personal protective equipment (PPE), deviations from standard operating procedures, and unsafe workplace practices.

The research object in this study is a coal-fired steam power plant where production and maintenance activities operate continuously for 24 hours. Based on workplace observations and company safety records, several unsafe behaviors were still identified despite the availability of safety procedures and OHS programs. These conditions indicate that the existence of safety policies, training, and protective equipment alone may not guarantee consistent employee safety behavior. A deeper understanding of the behavioral and organizational factors influencing safety behavior is therefore required to develop more effective BBS strategies. Previous studies have indicated that safety behavior may be influenced by various factors, including safety knowledge, safety attitude, safety motivation, safety equipment, teamwork, PPE availability, PPE monitoring, OHS training, organizational regulations, reward systems, and punishment mechanisms [2], [10], [11], [12]. However, most previous research has examined these factors individually rather than evaluating their simultaneous relationships within a comprehensive model. Furthermore, empirical studies applying Structural Equation Modeling (SEM) to analyze integrated BBS determinants in coal-fired power plant environments remain limited.

Structural Equation Modeling (SEM) provides an appropriate analytical approach for examining complex relationships among latent variables because it enables researchers to evaluate measurement models and structural relationships simultaneously [13], [14]. Through SEM analysis, this study seeks to identify the dominant individual and organizational factors that influence employee safety behavior and determine their relative contribution within an integrated BBS framework. Accordingly, this study aims to develop and evaluate an integrated Behavior-Based Safety determinant model by analyzing the relationship between individual and organizational factors and employee safety behavior in a coal-fired power plant environment. Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM) are applied to identify latent factor structures, validate the measurement model, and evaluate the proposed structural relationships. The novelty of this study lies in integrating multiple BBS determinants into a single structural model and empirically identifying the most influential factors affecting safety behavior in a high-risk power generation industry. The findings are expected to provide practical and theoretical contributions for strengthening safety management strategies and supporting the development of a sustainable zero-accident safety culture.

2. Methods

2.1 Research Design and Research Location

This study employed a quantitative cross-sectional research design to identify the determinants of Behavior-Based Safety (BBS) and examine their influence on employee safety behavior in a coal-fired steam power plant. The research was conducted at a power generation company where production and maintenance activities operate continuously for 24 hours. The research location was selected because coal-fired power plant operations involve complex processes and high-risk activities requiring effective occupational health and safety (OHS) management. Based on the company's Hazard Identification, Risk Assessment, and Control (HIRARC) documentation, several activities were categorized as high-risk, including hot work, high-voltage electrical work, confined space entry, working at height, lifting operations, chemical handling, radiation work, and underwater or near-water activities. The distribution of high-risk work activities recorded during the second semester of 2023 is presented in **Table 1**.

Table 1. High-Risk Work Activities Recorded During Semester 2 of 2023

No.	High-Risk Work Activities	Number of Work Activities (Ea)
1	Hot Work (Explosion Hazard)	68
2	High-Voltage Electrical Work (Vicinity)	82
3	Hot Work (Fire Hazard)	146
4	Confined Space Entry	76
5	Working at Height	93
6	Underwater and Near-Water Work	34
7	Radiation Work	7
8	Chemical Handling	24
9	Lifting Operations	46

2.2 Population, Data Collection, and Analysis

The study involved 200 employees from the production and maintenance departments, selected through probability sampling from a population of 379 workers. Respondents were required to have a minimum of three years of work experience to ensure sufficient familiarity with workplace safety practices. Data were collected using a structured questionnaire measuring individual and organizational safety factors, including safety knowledge, safety attitude, motivation, PPE availability, OHS training, OHS regulations, reward, punishment, and safety behavior. Instrument quality was evaluated through validity and reliability testing using Pearson correlation and Cronbach's alpha. The measurement model was assessed using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA), while Structural Equation Modeling (SEM) using AMOS 21 was applied to examine relationships among latent constructs. Model fit was evaluated using goodness-of-fit indices, and statistical significance was determined at $p < 0.05$ [13], [14], [15].

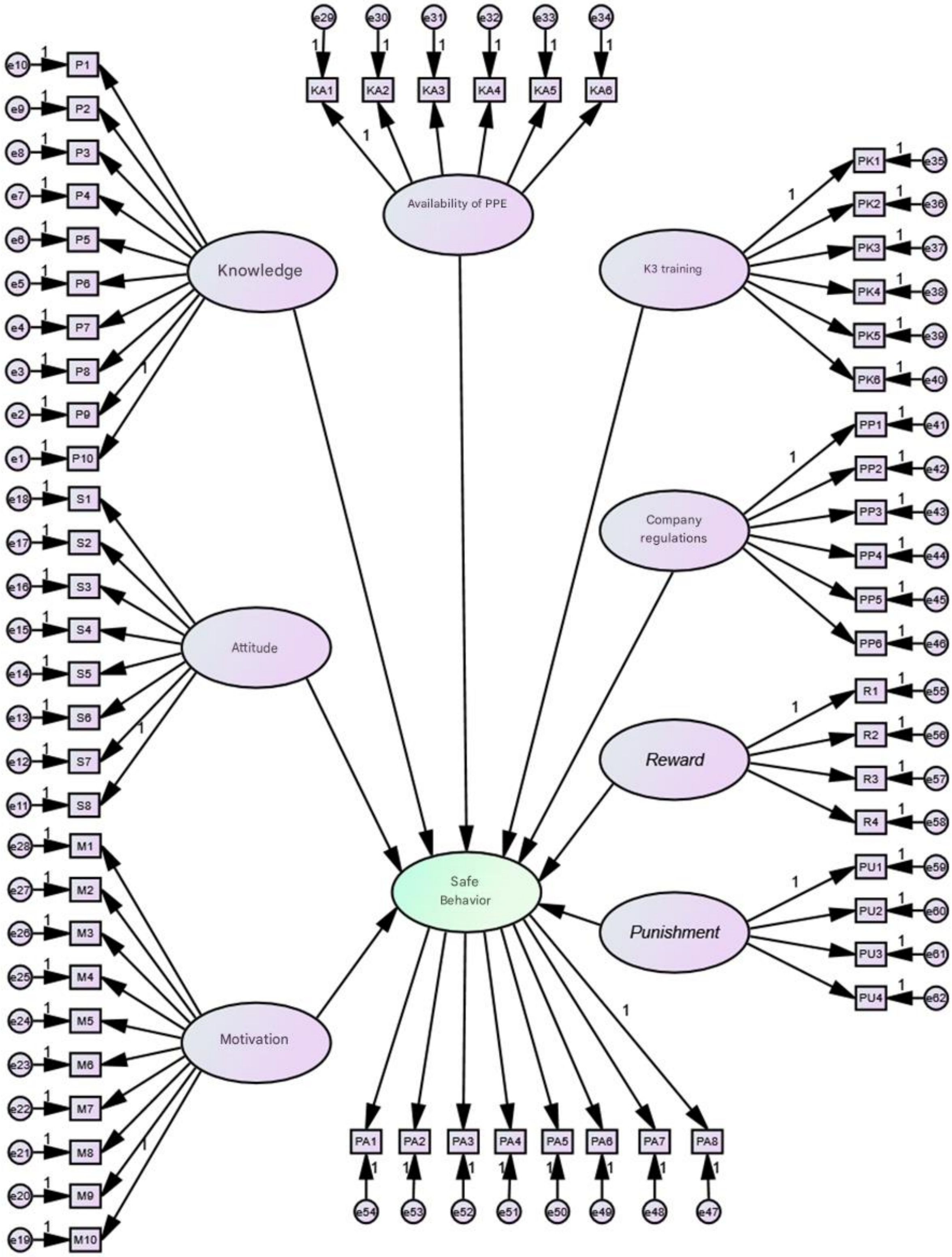

Figure 1. Initial Model of Relationships Between Variables

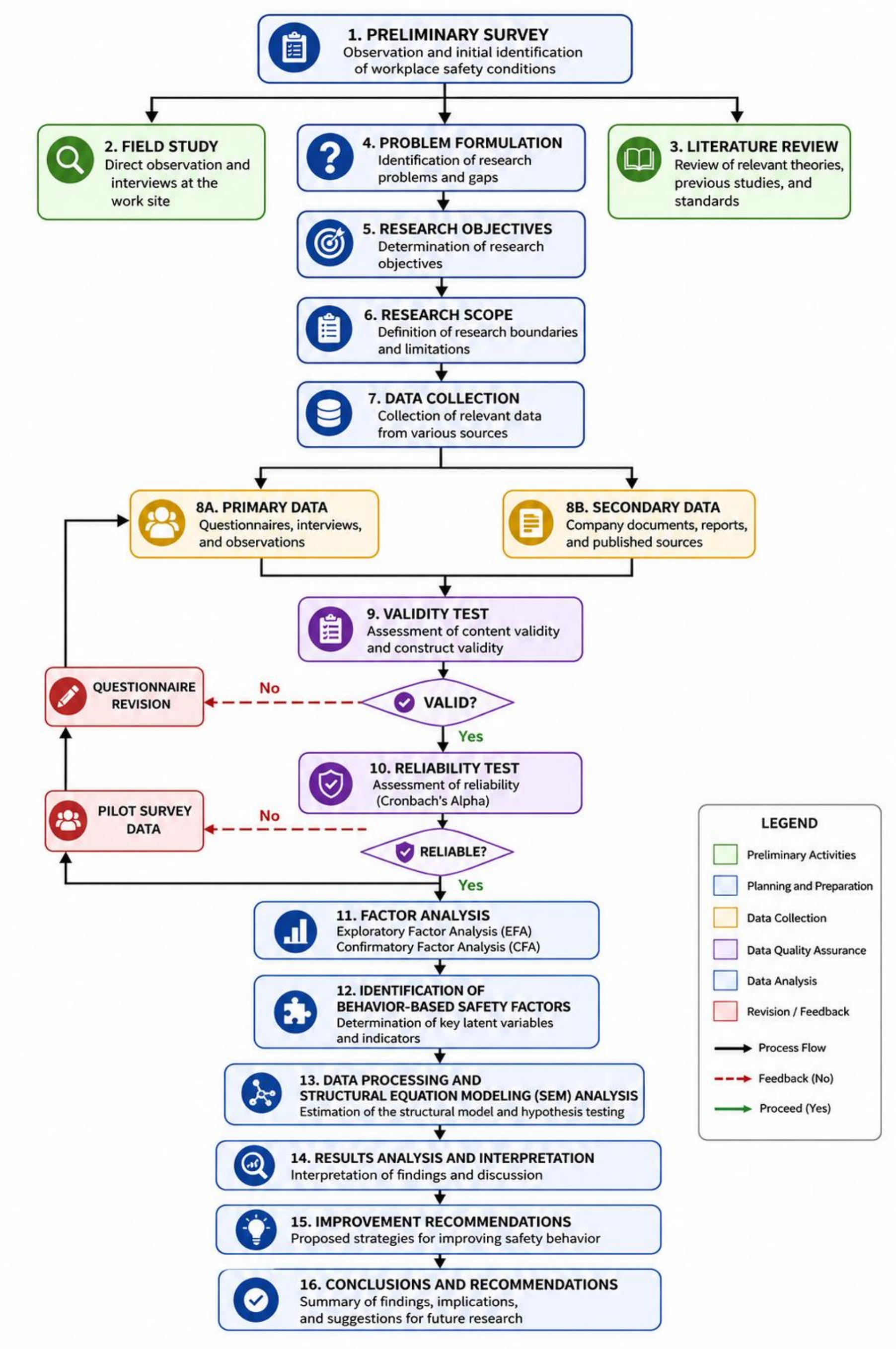

Figure 2. Flowchart Diagram of the research

3.Results and Discussion

3.1 Measurement Model Evaluation

3.1.1 Validity and Reliability Test

The validity of the research instrument was evaluated using Pearson correlation analysis by comparing item correlation coefficients with the critical value ($r = 0.138$) at a significance level of 0.05. All indicators showed correlation coefficients above the threshold with $p < 0.05$, indicating that all questionnaire items were valid and suitable for further analysis [13].

Table 2. Summary of Validity Test Results

Construct	Number of Items	Pearson Correlation (Min–Max)	*p*-value	Result
Safety Knowledge	6	0.217–0.269	<0.05	Valid
Safety Attitude	8	0.366–0.433	<0.05	Valid
Safety Motivation	10	0.167–0.476	<0.05	Valid
PPE Availability	6	0.293–0.418	<0.05	Valid
OHS Training	5	0.394–0.501	<0.05	Valid
OHS Regulations	6	0.581–0.616	<0.05	Valid
Safety Behavior	6	0.364–0.482	<0.05	Valid
Reward	5	0.381–0.515	<0.05	Valid
Punishment	5	0.428–0.449	<0.05	Valid

The reliability of each construct was assessed using Cronbach's alpha coefficient. A value above 0.60 indicates acceptable internal consistency [13]. As presented in **Table 3**, all constructs demonstrated good to excellent reliability, with Cronbach's alpha values ranging from 0.749 to 0.961. The validity and reliability results confirmed that all constructs were appropriate for further multivariate analysis using EFA, CFA, and SEM.

Table 3. Summary of Reliability Test Results

Construct	Cronbach's Alpha	Number of Items	Reliability
Safety Knowledge	0.884	6	Excellent
Safety Attitude	0.945	8	Excellent
Safety Motivation	0.83	10	Excellent
PPE Availability	0.749	6	Good
OHS Training	0.874	5	Excellent
OHS Regulations	0.959	6	Excellent
Safety Behavior	0.943	6	Excellent
Reward	0.934	5	Excellent
Punishment	0.961	5	Excellent

3.1.2 Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) was conducted using SPSS to identify the underlying factor structure of the measurement instrument. Sampling adequacy was evaluated using the Kaiser–Meyer–Olkin (KMO) index and Bartlett's Test of Sphericity. A KMO value above 0.50 and significant Bartlett's test indicate that the data are suitable for factor analysis [13].

Table 4. KMO and Bartlett's Test Results

Test	Initial EFA	Final EFA
KMO Measure of Sampling Adequacy	0.756	0.773
Bartlett's Test (χ^2)	12,176.73	11,601.20
df	1,596	1,378
Sig.	<0.001	<0.001

The initial EFA produced a KMO value of 0.756 with significant Bartlett's test results ($\chi^2 = 12{,}176.73$; $p < 0.001$). Four indicators were removed due to cross-loading, single-item factor formation, or factor loading below 0.40. After refinement, the KMO value increased to 0.773, indicating improved factor adequacy. The final EFA results revealed that the initial measurement structure developed into 11 latent dimensions. Safety Motivation was separated into Safety Equipment and Teamwork, while PPE-related indicators were differentiated into PPE Availability and PPE Monitoring. These findings indicate that safety behavior in high-risk power generation environments is influenced by multiple specific behavioral and organizational dimensions rather than broad constructs alone. The refined factor structure was subsequently evaluated using CFA.

3.1.3 Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis (CFA) was conducted using AMOS to validate the factor structure obtained from EFA and evaluate measurement model adequacy [13], [14].

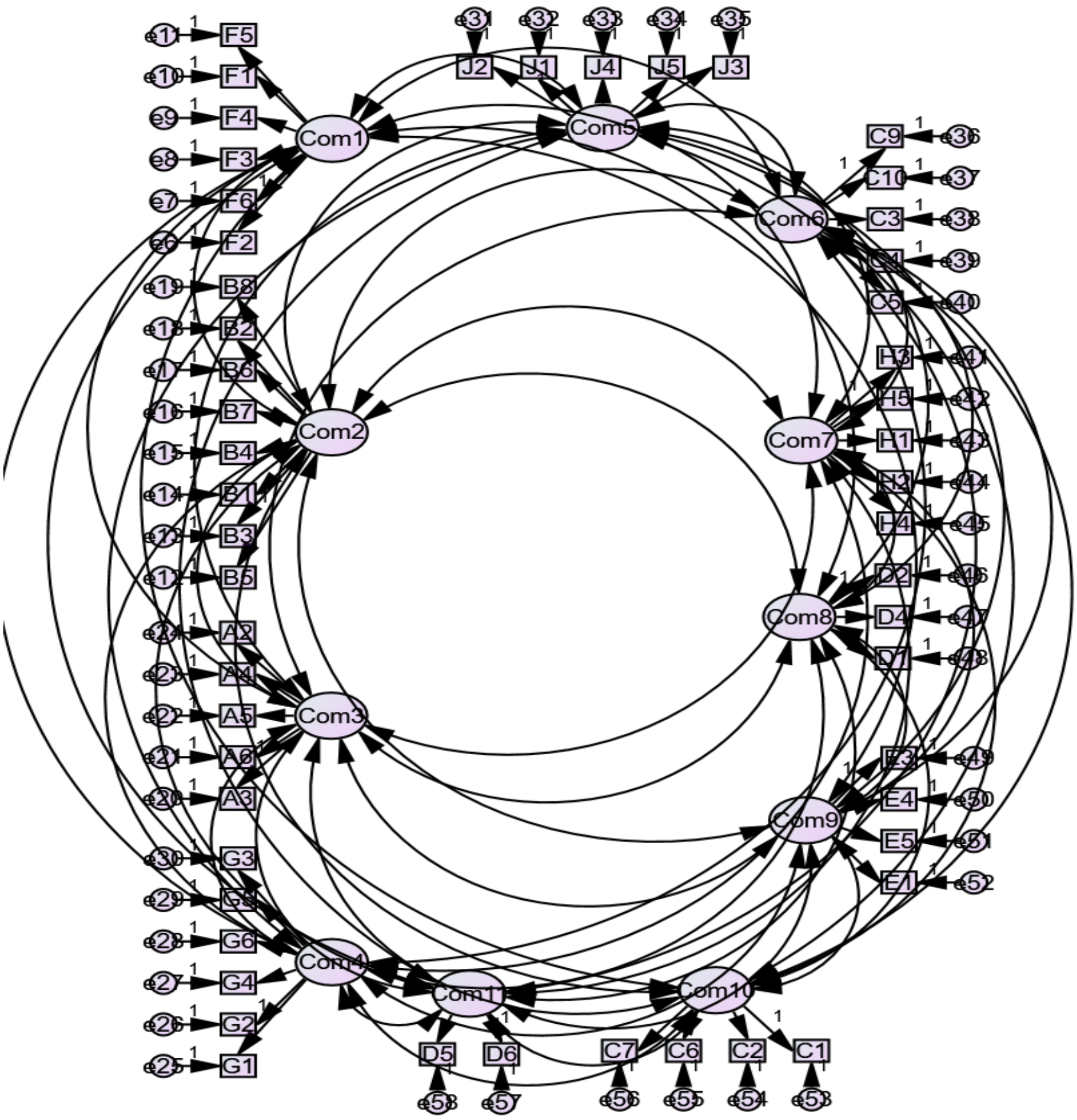

Figure 3. Initial CFA Model Results

The initial CFA model showed inadequate fit (χ^2 = 3,258.459; GFI = 0.647; CFI = 0.826; RMSEA = 0.089). Therefore, several indicators were removed to improve construct representation and model fit.

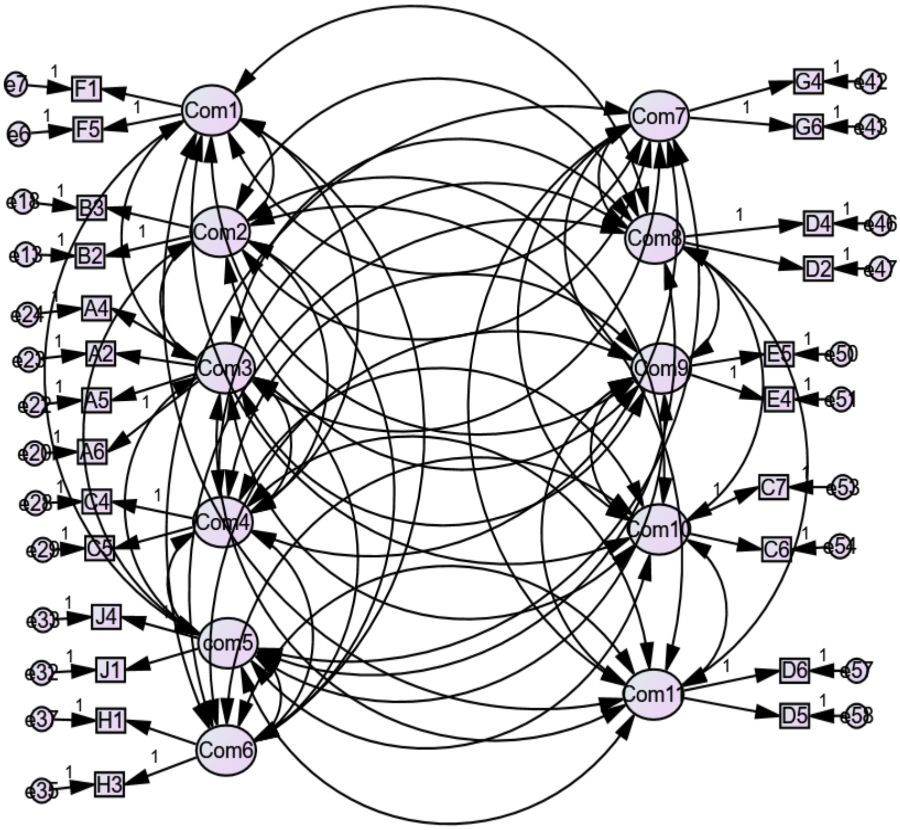

Figure 4. Final CFA Model Results

The final CFA model demonstrated acceptable fit indices (χ^2 = 219.888; p = 0.126; GFI = 0.922; NFI = 0.936; TLI = 0.990; CFI = 0.993; RMSEA = 0.024), indicating that the measurement model adequately represented the observed data.

Table 5. Summary of Construct Refinement after EFA and CFA

Original Construct	Initial Indicators	Retained Indicators	Final Construct
Safety Knowledge	6	4	Safety Knowledge
Safety Attitude	8	2	Safety Attitude
Safety Motivation	10	2	Safety Equipment
PPE Availability	6	2	PPE Availability
OHS Training	5	2	OHS Training
OHS Regulations	6	2	OHS Regulations
Safety Behavior	6	2	Safety Behavior
Reward	5	2	Reward
Punishment	5	2	Punishment

3.2 Structural Model Analysis (SEM)

Structural Equation Modeling (SEM) was performed using AMOS to examine the relationships between the identified BBS determinants and Safety Behavior.

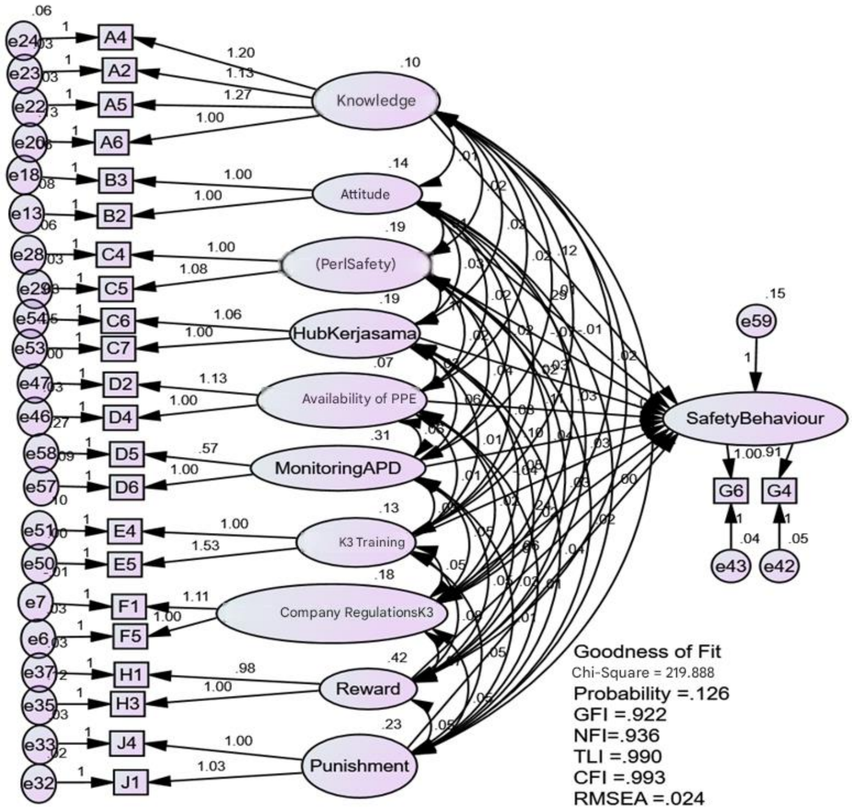

Figure 5. SEM Model

The structural model demonstrated good model fit, with χ^2 = 219.888 (p = 0.126), GFI = 0.922, TLI = 0.990, CFI = 0.993, and RMSEA = 0.024.

Table 6. Goodness-of-Fit Indices

Fit Index	Recommended Value	Result	Model Fit
Chi-square (*p*-value)	$p > 0.05$	0.126	Good
GFI	> 0.90	0.922	Good
TLI	> 0.90	0.99	Excellent
CFI	> 0.90	0.993	Excellent
RMSEA	< 0.08	0.024	Excellent

Hypothesis testing showed that Safety Attitude significantly influenced Safety Behavior (CR = 2.887; p = 0.004), and OHS Regulations significantly influenced Safety Behavior (CR = 2.930; p = 0.003). Other determinants did not demonstrate significant relationships (p > 0.05).

Table 7. SEM Hypothesis Testing Results

Hypothesis	Relationship	CR	*p*-value	Result
H1	Safety Knowledge → Safety Behavior	1.091	0.275	Not Supported
H2	Safety Attitude → Safety Behavior	2.887	0.004	**Supported**
H3	Safety Equipment → Safety Behavior	−0.684	0.494	Not Supported
H4	Teamwork → Safety Behavior	−0.271	0.786	Not Supported
H5	PPE Availability → Safety Behavior	0.846	0.397	Not Supported
H6	PPE Monitoring → Safety Behavior	1.457	0.145	Not Supported
H7	OHS Training → Safety Behavior	−0.403	0.687	Not Supported
H8	OHS Regulations → Safety Behavior	2.93	0.003	**Supported**
H9	Reward → Safety Behavior	1.164	0.244	Not Supported
H10	Punishment → Safety Behavior	0.403	0.687	Not Supported

3.3 Discussion of Findings

The SEM results indicate that Safety Attitude and OHS Regulations are the primary determinants of Safety Behavior in the studied power generation environment. The significant influence of Safety Attitude supports the BBS perspective that sustainable safety improvement requires employees' internal commitment and active involvement in safe work practices [6], [8].

The significant relationship between OHS Regulations and Safety Behavior highlights the importance of organizational safety systems in shaping employee actions. Clear procedures, permit-to-work systems, hazard identification practices, and consistent supervision provide external mechanisms that reinforce expected safety behaviors [4], [5].

Conversely, Safety Knowledge, training, PPE availability, reward, and punishment did not significantly influence Safety Behavior when evaluated simultaneously. This indicates that safety behavior cannot be improved solely through information transfer, resource provision, or external control mechanisms. Instead, behavioral change requires integration between individual safety attitudes and organizational safety practices.

3.4 Practical Implications

Based on SEM findings, improvement strategies should prioritize strengthening Safety Attitude and OHS Regulations. Organizations should enhance employee safety commitment through safety briefings, behavioral feedback, peer intervention programs, and active hazard reporting.

Furthermore, consistent implementation of OHS regulations should be maintained through permit-to-work compliance, routine supervision, safety audits, and corrective action monitoring. These approaches may strengthen BBS implementation and support sustainable safety performance improvement.

4. Conclusion

This study identified the determinants of Behavior-Based Safety (BBS) in a coal-fired power generation company using EFA, CFA, and SEM approaches. The results revealed that Safety Attitude ($p = 0.004$) and OHS Regulations ($p = 0.003$) were the only significant factors influencing Safety Behavior, while Safety Knowledge, Safety Equipment, Teamwork, PPE Availability, PPE Monitoring, OHS Training, Reward, and Punishment showed no significant effects ($p > 0.05$).

These findings indicate that improving safety behavior requires strengthening employees' safety attitudes and ensuring consistent implementation of organizational OHS regulations. Therefore, safety improvement strategies should focus on developing safety-oriented values, effective communication, behavioral feedback, and continuous enforcement of safety procedures. This integrated behavioral and organizational approach can support sustainable BBS implementation and the achievement of a zero-accident safety culture.

Acknowledgement

The authors would like to express their gratitude to A Power Generation Company, particularly the Safety, Health, and Environment (SHE) Department, for providing research permission, technical support, and access to occupational safety data. The authors also thank the management and employees of the Production and Maintenance Departments for their cooperation during data collection. Appreciation is also extended to the Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember (ITS), for its academic support and research facilities.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

Funding - No funding information from the authors.

Availability of data and materials - All data is available from the authors.

Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

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