

The Impact of Safety Factors on Safety Performance (Study on Hydroelectric Power Plants in Sumatra)

Sarah Freshima^{a*}, Putu Artama Wiguna^a

Correspondence

^aDepartment of Civil Engineering,
Institut Teknologi Sepuluh
Nopember, Kampus ITS Sukolilo,
Surabaya 60111, Indonesia.

Corresponding author email address:
sarahtampubolon3@gmail.com

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Abstract

This research is motivated by the urgency of improving occupational safety in dam maintenance activities at Hydroelectric Power Plants, particularly in the Sumatra region. Although not included in the category of new construction projects, dam structural maintenance and repair activities still contain high risks, especially the potential for technical failures such as seepage which globally is the main cause of dam collapse. At the national level, hydroelectric power plants play a vital role in supporting energy security, but the implementation of Occupational Safety and Health programs is still not optimal. This is reflected in the absence of hydroelectric power plants in Sumatra that have received the Zero Accident award, as well as the number of recurring occupational accidents at several hydroelectric power plants, such as at plants X and Y, over the past five years. This situation emphasizes the need for an in-depth study of the factors that influence the effectiveness of occupational safety systems in the hydroelectric power plant maintenance project sector. This study aims to analyze the influence of safety leadership, safety climate, safety culture, and safety behavior on safety performance, using a quantitative approach with the Partial Least Squares Structural Equation Modeling (SEM-PLS) method. A total of 117 respondents were selected using purposive cluster sampling. The analysis shows that safety culture has the strongest positive influence on safety performance. This research confirms that optimal safety performance can only be achieved through the synergy between a strong safety culture, ingrained safety behaviors, supportive leadership, and a safety climate.

Keywords

Safety Leadership, Safety Climate, Safety Culture, Safety Behavior, Safety Performance, SEM Methods, Hydroelectric Power Plants.

INTRODUCTION

Hydropower plants are a critical component of national infrastructure, playing a crucial role in energy generation and reducing carbon emissions. In Sumatra, there are currently 71 hydropower plants spread across three main regions: North Sumatra, Central Sumatra, and South Sumatra.

One key element of these facilities is the dam structure, which is essential for retaining and regulating water flow. Routine maintenance activities such as grouting, drilling, and inspections on or within the dam body are crucial to ensuring structural integrity and operational safety. However, these tasks are high-risk due to the underground location, limited working space, and exposure to potentially hazardous conditions.

Despite their importance and contribution to sustainable energy, not a single hydropower plant in Sumatra has received the government's Zero Accident Award to date. This highlights the urgent need for improved safety measures, improved maintenance protocols, and stricter oversight to ensure worker well being and the long-term reliability of these vital assets.

Hydroelectric power plants are critical infrastructure in the national energy system and require consistent maintenance to ensure their operational reliability. Among them, dam structures play a central role in regulating and controlling water flow. However, maintenance activities such as grouting and drilling dam bodies are categorized as high-risk operations due to their underground operation and exposure to hazardous working conditions. In Sumatra alone, there are 71 hydroelectric power plants spread across three main regions: North Sumatra, Central Sumatra, and South Sumatra. Despite their significant contribution to the national energy supply, not a single hydroelectric power plant in Sumatra has received the government's prestigious Zero Accident Award, highlighting the ongoing challenges in occupational safety management. The Minister of manpower revealed that in 2023, the number of workplace accidents in Indonesia reached 370,747. Of these, 93.83% involved wage earners, 5.37% involved non-wage earners, and 0.80% involved construction service participants.

This data indicates that occupational safety remains a crucial issue, with hydroelectric power plants identified as one of the sectors contributing to the increase in workplace accidents. Therefore, it is crucial to examine the factors influencing safety performance in hydroelectric power plants to develop more effective strategies to prevent accidents and achieve the zero accident.

Hydroelectric Power Plants X and Y have experienced several workplace accidents resulting from both human error and equipment failure. At Hydroelectric Power Plant X, workplace accident data from 2019 to 2023 recorded 13 cases, all of which fell into the restricted work case category. This pattern reflects a tendency for recurring workplace incidents and highlights the need for a comprehensive evaluation of the existing occupational safety system. In comparison, Hydroelectric power plant Y recorded 25 cases during the same period, most of which were categorized as first aid cases. These findings indicate that the implementation of the occupational safety and health management system at both plants remains inadequate and requires significant improvement. Therefore, further research is needed to analyze the factors that influence safety performance in hydropower plants so that targeted strategies can be developed to reduce workplace accidents and achieve the goal of zero accidents.

Previous research also shows that workplace accidents in the hydropower sector occur among workers regardless of whether they have implemented standard operating procedures. Similarly, a study found that accidents occurred among workers in a hydropower tunnel construction project, both with and without occupational safety and health standards. Field survey results showed that 20 workers (29.9%) experienced workplace accidents, while 47 workers (70.1%) did not. These findings suggest that implementing occupational safety and health standards or standard operating procedures alone does not fully guarantee workplace safety, necessitating a more comprehensive approach.

Such an approach requires a deeper understanding of the underlying factors influencing safety performance. Key determinants include safety culture, safety climate, and safety behavior, all of which are strongly influenced by leadership. Therefore, examining the interaction of these factors is crucial to providing empirical evidence and formulating effective strategies to improve safety performance in hydropower plants.

Hydroelectric dam maintenance projects are classified as heavy engineering construction activities with a high level of risk, especially in jobs such as grouting and drilling, which require the implementation of strict work safety systems. Standard operating procedures in construction include planning and evaluation stages aimed at preventing accidents and occupational diseases [1]. The complexity of the work environment, combined with the diverse technical backgrounds of workers, makes work safety a strategic aspect that requires a multidimensional approach.

One key factor is safety leadership, which is the ability of managers to build safety awareness and compliance through role modeling and communication.

The role of leaders in shaping safe work behaviors is crucial. Other studies also show that leadership contributes significantly to safety culture and behavior [2,3,4].

Within this multidimensional framework, safety climate reflects workers' collective perceptions of safety priorities within an organization. This climate is dynamic and shaped by open communication and consistent managerial actions [5]. Over time, these perceptions contribute to the development of a safety culture, encompassing values and attitudes that embed safety into the organization's identity. A strong safety culture is reinforced by leadership commitment, open reporting mechanisms, and continuous learning processes [6].

From an individual perspective, safety behavior represents workers' compliance and active participation in maintaining safety. Behavioral characteristics are divided into two dimensions: safety compliance and safety participation, demonstrated through practices such as the use of personal protective equipment (PPE), participation in training, and incident reporting [7]. Ultimately, safety performance reflects the overall effectiveness of the workplace safety system, with indicators such as incident frequency and level of adherence to procedures [8]. Both individual and organizational factors including leadership, safety culture, and the work environment play important roles in determining overall safety performance [9].

RESEARCH SIGNIFICANCE

This study focuses on dam maintenance projects at several hydroelectric power plants in Sumatra. The research sample consisted of employees and engineering staff directly involved in the maintenance projects. The analysis technique used was partial least squares structural equation modeling (SEM-PLS) to examine the relationships between latent variables. The purpose of this study was to analyze the direct and indirect effects of safety leadership, safety climate, safety culture, and safety behavior on safety performance.

METHODOLOGY

This study uses a quantitative confirmatory approach with the partial least squares structural equation modeling (SEM-PLS) method. The aim is to examine the direct and indirect influences between latent variables: safety leadership, safety climate, safety culture, safety behavior, and safety performance.

A. LITERATURE REVIEW

The definition of the safety leadership variable will be explained along with several other variables, namely safety climate, safety culture, and safety behavior, which as a whole have the potential to influence safety performance in a project.

1) Safety Leadership

Safety leadership has long been recognized with the term "safety leader" first appearing in a 1919 National

Safety Council publication, which emphasized the importance of exemplary leadership in preventing accidents [10]. Several studies demonstrate that safety leadership positively impacts safety performance, suggesting that the better the leadership implemented, the more optimal the safety performance achieved [2,11,12].

2) Safety Climate

Safety climate is defined as employee perceptions of safety values and priorities within an organization at a given time [13,14]. Situational and relatively unstable, safety climate can change depending on environmental conditions, communication, and applicable policies. Factors influencing safety climate include communication, procedural clarity, work pressure, use of personal protective equipment (PPE), employee relationships, and safety regulations. In addition to physical conditions, psychological and social aspects also play a significant role, as emotions, anxiety levels, and the employee group's commitment to safety can shape work attitudes and behaviors [15].

3) Safety Culture

Safety culture is often viewed alongside safety climate because they both serve as key principles in OHS management, encompassing attitudes, values, continuous learning, and improved safety mindsets. This concept was first introduced following the 1986 Chernobyl accident, when the International Atomic Energy Agency defined it as the characteristics and behaviors of organizations and individuals who place safety as a top priority [16]. Safety culture reflects commitment, responsibility, self-discipline, and the prevention of complacency in work practices.

To build a strong safety culture, organizations need to instill five key elements. These five cultural elements are an information culture (collecting and analyzing safety data), a reporting culture (openness in reporting hazards without fear of sanctions), a learning culture (leveraging mistakes for improvement), a flexible culture (the ability to adapt to the environment), and a fair culture (fair and transparent enforcement of rules). A positive safety culture has been shown to play a role in reducing accident rates, increasing workers' sense of security, and impacting productivity, motivation, and job satisfaction.

4) Safety Behaviour

Safety behavior is an individual's actions to protect themselves and others in accordance with safety regulations to prevent workplace accidents [3]. This behavior reflects values, beliefs, and attitudes toward safety that are closely related to organizational culture. Safety behavior can be observed through adherence to procedures, use of PPE, awareness of potential hazards, and reporting or warning of unsafe conditions. Furthermore, safety behavior includes active participation such as attending training, providing feedback, or assisting coworkers with safety issues. Previous research has divided safety behavior into two dimensions: safety compliance, which is basic adherence to procedures, and safety participation, which

is voluntary involvement in supporting an overall safety culture. Thus, safety behavior plays a crucial role in building a safe and productive work environment.

5) Safety performance

One of the key factors in improving project efficiency and productivity is enhancing safety performance. Safety performance evaluation reflects the success of management in preventing accidents and occupational diseases, while also contributing to overall productivity. It is commonly measured through accident frequency, incident rate, and severity rate [2]. Safety performance represents the overall outcome of safety management, which can be assessed through aspects such as safety equipment, safety actions, safety management, accident investigation statistics, safety training, and organizational safety [5]. A safety performance model should consider performance elements, determinants, and background factors, both at the individual level such as roles, skills, and experience and at the organizational level, including leadership, climate, culture, and behavior.

B. RESEARCH HYPOTHESIS

This research uses a quantitative paradigm with a confirmatory approach to test hypotheses based on empirical data. The primary method is a questionnaire survey, which was used to collect numerical data from a sample population. The focus of the research is to examine the relationships between safety leadership, safety culture, safety climate, and safety behavior and safety performance in hydroelectric power plants. A conceptual research model was designed based on a previous literature review and presented in the form of hypotheses and a research framework.

The research concept regarding the relationships between variables was then designed to form a research model and hypotheses regarding the relationship between safety leadership, safety culture, safety climate, and safety behavior and safety performance in hydroelectric power plants. An illustration of this concept is presented in the figure below.

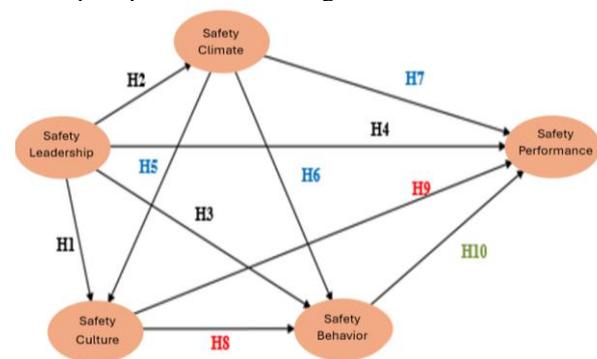


Figure 1 Research Hypothesis

Based on the results of previous studies, the following hypotheses can be made:

- H1: Safety leadership influences safety culture
- H2: Safety leadership influences safety climate
- H3: Safety leadership influences safety behavior

- H4: Safety leadership influences safety performance
- H5: Safety climate influences safety culture.
- H6: Safety climate influences safety behavior.
- H7: Safety climate influences safety performance.
- H8: Safety culture influences safety behavior.
- H9: Safety culture influences safety performance.
- H10: Safety behavior influences safety performance.

C. POPULATION AND SAMPLE

The sampling process in this study was designed to ensure the relevance and validity of the collected data. To achieve this, this study selected a sample from the target population of hydropower plant workers involved in dam maintenance projects in North, Central, and South Sumatra. The sampling criteria required participants to be actively involved in dam maintenance activities, have at least one year of work experience, have a minimum high school education or equivalent, and hold a technical staff position overseeing dam operations. These professionals generally come from engineering disciplines such as civil, mechanical, electrical, industrial, or software engineering, and are responsible for a variety of technical tasks, including the design, construction, testing, and maintenance of systems and equipment.

Sampling technique is a method used to determine the sample in a study [17]. Sampling techniques are generally divided into two main categories: probability sampling and non-probability sampling. This study applies probability sampling, a method that provides an equal opportunity for each member of the population to be selected as part of the sample [17]. Because the population in this study has diverse characteristics and consists of subpopulations of varying sizes, the sampling

technique is further adjusted. Specifically, this study uses purposive cluster sampling, a method of taking representative samples from each population cluster based on predetermined criteria to ensure that the sample truly reflects the entire population. This approach was chosen because hydroelectric dam maintenance workers are spread across various regions and project locations, making cluster according to based sampling the most effective way to capture the diversity of experiences and safety practices among workers.

D. OPERATIONAL DEFINITION OF RESEARCH VARIABLES

Research variables are measurable characteristics that vary across objects to address research questions, while indicators are indicators that enable measurement of these variables. The identification of variables and indicators in this study was based on a literature review of relevant journals, which was then adapted to the context of safety management in hydropower plants. Details are presented in Table 1.

E. RESEARCH INSTRUMENTS

The research instrument used a questionnaire completed independently by respondents. The questionnaire consisted of an introduction, demographic data, screening questions, and questions based on research variable indicators, namely leadership, climate, culture, behavior, and occupational safety performance. Each section of the questionnaire was structured based on references from various previous studies. All questions used a Likert scale and were distributed to various levels of positions directly involved in the hydropower plant maintenance project, from managers to technical staff.

Table 1 Indicator and Operational Definition

Research variables	Construct Factor	Code	Operational Definition	Sources
Safety leadership	safety motivation	KEP 1	readiness to motivate safety	[2],[21],[18],[8]
	safety policy	KEP 2	emphasis on safety in the workplace	
	security concerns	KEP 3	use of personal protective equipment	
	leadership examples	KEP 4	set high standards for performance and apply them in work	
	action orientation	KEP 5	establishes that a good example is the behavior demonstrated	
	feedback and recognition	KEP 6	listen to ideas and suggestions from your work group to make decisions that will benefit your work group	
	showing concern	KEP 7	show concern for team members who have worked well	
Safety Climate	Understanding procedures	IK 1	Individuals understand occupational risks and the steps taken to manage them	[19],[15],[4],[20],[8]
	safety training program	IK 2	Training according to job risk needs	
	Work ban	IK 3	Workers are not forced to work if it is dangerous	
	Management attitude towards safety	IK 4	strict monitoring of work safety implementation even though the work is carried out outside the schedule	
	preliminary investigation	IK 5	Anticipate every opportunity for work safety hazards (even if it costs money and time)	
	occupational safety data information	IK 6	create detailed data regarding safety reports to workers (such as types of injuries, hazard prone areas)	

Research variables	Construct Factor	Code	Operational Definition	Sources
Safety culture	Information culture	BDY 1	ease of hazard information related to operational processes	[2], [15], [9], [5], [8]
	Risk acceptance	BDY 2	hazard information related to production materials/ingredients	
	Learning culture	BDY 3	workplace accident investigation drive	
	Employee engagement	BDY 4	Ready to take over the situation in emergency conditions	
	Management commitment	BDY 5	Following up on actions from accident inspections	
	Individual risk assessment	BDY 6	Consider the risk of hazards before starting work activities	
Safety behavior	occupational safety as a priority	PRL 1	Occupational safety as a top priority	[2], [7], [9], [8]
	Comply with rules, regulations and procedures	PRL 2	Comply with rules, regulations and procedures	
	use personal protective equipment	PRL 3	Comply with the use policy (PPE)	
	safety participation	PRL 4	participation in safety meetings	
	implementation of safety rules	PRL 5	Ignoring safety rules to achieve work targets	
	Volunteer in carrying out safety duties	PRL 6	Carry out safety duties voluntarily	
Safety performance	Safety compliance	KIN 2	Each individual complies with established safety policies and procedures.	[15], [22], [14], [19], [2]
	Responsibility for personal safety	KIN 3	have self-control over work safety in acting	
	creative action	KIN 4	ability to identify safety performance	
	safety compliance	KIN 5	carry out work safely	

F. DATA ANALYSIS

After the initial analysis, respondent profiles were identified based on demographic characteristics such as gender, age, education, and field of employment, and presented in pie charts to illustrate the distribution. Subsequently, the outer model evaluation was carried out to test indicator reliability (loading > 0.708), convergent validity ($AVE \geq 0.5$), and discriminant validity using the Fornell-Larcker criterion and cross-loading.

The inner model evaluation assessed structural relationships between latent variables through key indicators such as R^2 , f^2 , and Q^2 . The R^2 value reflects the explanatory power of exogenous variables on endogenous variables, f^2 measures the effect size, and Q^2 evaluates predictive relevance. This step ensured both the internal consistency and external validity of the model.

Hypothesis testing was then performed using path coefficients, t-values, and p-values, with hypotheses accepted at $p < 0.05$. Goodness of Fit (GoF) was also calculated to assess overall model suitability, with values categorized as small (0.10), medium (0.25), and large (0.36). Although not the sole indicator of model validity, GoF supports the robustness of the structural model. Finally, results were discussed to explain the influence of each independent variable on safety performance in hydropower projects in Sumatra.

RESULTS AND DISCUSSIONS

Data collection was conducted from March 25 to May 2, 2025, using a questionnaire distributed to hydropower engineering staff in Sumatra. The population was divided into three regions: North Sumatra, Central Sumatra, and South Sumatra, encompassing 71 hydropower plants with an estimated 1,065 engineering staff. To ensure representation, a cluster sampling technique was applied, resulting in an initial sample of 143 respondents across the three regions.

Based on the selection criteria, 36 respondents were excluded due to insufficient qualifications. The final distribution consisted of 60 samples from eight hydropower plants in North Sumatra, 27 samples from one hydropower plant in Central Sumatra, and 30 samples from two large hydropower plants in South Sumatra.

In total, 117 respondents met the criteria, and their data were used for analysis. This distribution reflects the characteristics of hydropower generation in Sumatra, which is largely dominated by large capacity hydropower plants. This process ensured that the collected data were valid and representative of actual field conditions.

A. RESPONDENT PROFILE RECAPITULATION

Based on the analysis of 117 respondents, the majority were male (83%) and in the productive age range of 25-

30 years (62%), reflecting the predominance of young male workers in hydroelectric power plant maintenance projects that demand physical fitness and mobility. Most respondents (75%) held a bachelor's degree (S1), suggesting adequate competency in technical and occupational safety aspects. In terms of job placement, the largest proportion came from Engineering, Maintenance, and Civil Engineering units, which are directly related to operational and technical activities.

Work experience was also concentrated in the range of 3-10 years (53%), indicating the dominance of workers with intermediate experience. Additionally, most respondents (88%) were employed in large-scale hydroelectric power plants, confirming the study's focus on the management and maintenance of major hydropower infrastructure.

B. DESCRIPTIVE ANALYSIS OF VARIABLES

The descriptive analysis illustrates respondents' perceptions of each indicator within the five research variables: safety leadership, safety climate, safety culture, safety behavior, and safety performance. This analysis aimed to provide an initial understanding of respondents' agreement with occupational safety aspects measured in the questionnaire.

Descriptive analysis of the five research variables consisting of safety leadership, safety climate, safety culture, safety behavior, and safety performance has shown a consistently high level of respondent agreement regarding the importance of occupational safety in hydropower operations. For safety leadership, the highest score was found in occupational safety motivation (4.49), supported by positive evaluations of perspective, credibility, and communication, indicating leadership's crucial role in shaping a safe work environment. Similarly, the safety climate dimension reflected strong results, with transparency in safety data (4.42) and concrete managerial actions (4.37) perceived as key drivers of a positive safety atmosphere.

Safety culture also demonstrated strong support, with management commitment (4.50), individual risk assessment (4.48), and employee contribution (4.47) emphasizing that both leadership and worker participation are essential in managing risks. Safety behavior was deeply embedded in daily practices, with occupational safety priority (4.60), PPE use (4.47), and compliance (4.44) showing that employees consistently upheld safety as a core value. Finally, safety performance indicators such as safety compliance (4.59), personal safety (4.56), and procedural adherence (4.55) confirmed high overall performance, though creative safety initiatives scored lower (4.25). Collectively, these findings highlight a well-established safety system supported by leadership, culture, behavior, and compliance in big hydropower operations.

C. STRUCTURAL MODEL EVALUATION (INNER MODEL)

Internal model analysis was conducted to understand the relationship between latent variables within the

theoretical framework and to validate the model using empirical data. This evaluation included R^2 , f^2 , and Q^2 values, as well as path coefficient testing using T-statistics and P-values to determine the significance of the relationship. The coefficient of determination (R^2) measures the influence of the independent variable on the dependent variable, with values ranging from 0 to 1. R^2 values of 0.75, 0.50, and 0.25 are categorized as substantial, moderate, and weak, respectively [6].

Table 2 Influence between variables

Construct	R Square	R Square Adjusted	Remark
Safety climate	0.623	0.62	Moderate
Safety culture	0.683	0.677	Moderate
Safety behaviour	0.72	0.712	Moderate
Safety performance	0.779	0.772	Substantial

Based on the research results, all constructs had R^2 values above 0.50, indicating good predictive ability of the research model. Safety Performance recorded the highest R^2 value (0.779), meaning 77.9% of the variation can be explained by the model. Safety behavior also showed a high R^2 value (0.72), approaching the substantial category. This finding confirms that the model is reliable in explaining variation between constructs and is suitable for analyzing relationships between the variables.

The f^2 value measures the magnitude of the effect of exogenous variables on endogenous variables, which are categorized as small (0.02), medium (0.15), and large (0.35). The results indicate that Safety Culture has a moderate effect on Safety Performance ($f^2 = 0.216$) and a small effect on Safety behavior ($f^2 = 0.136$). Safety Climate has a moderate influence on Safety Culture ($f^2 = 0.265$) and Safety behavior ($f^2 = 0.192$), but its influence on Safety Performance is negligible ($f^2 = 0.008$). Safety Performance itself has a moderate influence on Safety Behavior ($f^2 = 0.159$). Meanwhile, Safety Leadership shows a very large influence on Safety Climate ($f^2 = 1.651$), a moderate influence on Safety Culture ($f^2 = 0.191$), but only a small influence on Safety Performance ($f^2 = 0.014$) and Safety Behavior ($f^2 = 0.022$).

Overall, the analysis shows that several constructs, particularly Safety Climate and Safety Leadership, contribute significantly to other variables in the model. The influence of Safety Leadership on Safety Climate was found to be highly significant, highlighting its dominant role in shaping organizational perceptions of safety climate.

The Q^2 value, obtained through a blindfolding procedure using the Sum of Squared Errors (SSE) and the Sum of Squared Observations (SSO), was used to assess the predictive relevance of the structural model. A Q^2 value greater than zero indicates predictive relevance, while a value closer to 1 indicates strong predictive power. Based on the results, all constructs in this study produced Q^2 values above zero, confirming the model's strong predictive relevance. This strengthens

the conclusion that the developed model is reliable and robust in predicting variations in safety performance in hydropower plant operations.

Table 3 Prediction Relevance Test

Constructs	SSO	SSE	Q ²
Safety Culture	468	237.633	0.492
Safety Climate	585	345.373	0.41
Safety Performance	468	186.873	0.601
Safety Behavior	585	288.172	0.507

Overall, all constructs had Q² values above 0.35, thus categorizing them as having high predictive ability. Therefore, it can be concluded that the structural model in this study has good predictive relevance and is suitable for explaining the endogenous variables studied.

D. DIRECT INFLUENCE BETWEEN VARIABLES

Based on the results of the hypothesis testing, several relationships between constructs were found to be statistically significant, while others were not. Significant relationships were indicated by high path coefficient values and t-statistics exceeding the critical threshold of 1.96 at the 5% significance level, accompanied by a P-value less than 0.05. These findings confirmed the strong theoretical relationships between constructs and provided empirical evidence supporting the research model.

Meanwhile, several relationships were found to be insignificant, as indicated by relatively low path coefficient values and t-statistics below the critical threshold. This suggests that while the theoretical framework posits these influences, the empirical evidence does not fully support them in the context of hydropower operations in Sumatra. These results highlight the complexity of occupational safety dynamics, where certain constructs such as leadership and safety climate can exert strong influences, while others exhibit weaker or indirect effects.

Table 4 Direct influence between constructs

HYPOTHESIS	Path Coef.	T Statistics	P Values	Remarks
Safety Leadership -> Safety Culture (H1)	0.401	2.712	0.007	Accepted
Safety Leadership -> Safety Climate (H2)	0.789	12.507	0.000	Accepted
Safety Leadership -> Safety Behavior (H3)	0.139	1.339	0.181	Rejected
Safety Leadership -> Safety Performance (H4)	0.100	1.124	0.262	Rejected
Safety Climate -> Safety Culture (H5)	0.472	3.478	0.001	Accepted
Safety Climate -> Safety Behavior (H6)	0.424	2.941	0.003	Accepted

HYPOTHESIS	Path Coef.	T Statistics	P Values	Remarks
Safety Climate -> Safety Performance (H7)	0.086	0.725	0.469	Rejected
Safety Culture -> Safety Behavior (H8)	0.347	2.183	0.029	Accepted
Safety Culture -> Safety Performance (H9)	0.413	2.940	0.003	Accepted
Safety Behavior -> Safety Performance (H10)	0.354	2.912	0.004	Accepted

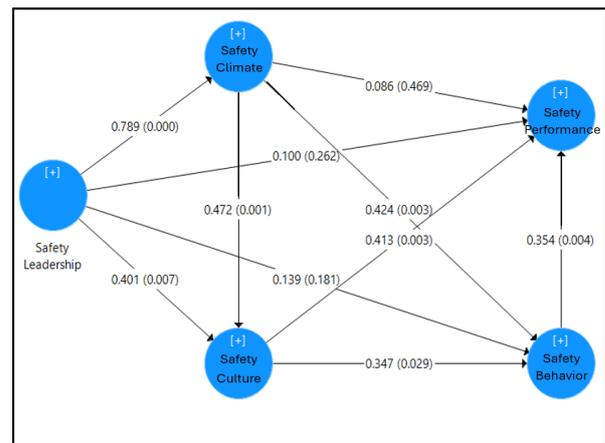


Figure 2 Results of Path Coefficients of Direct Influence

Hypothesis testing revealed varying relationships among the studied constructs. Safety leadership was found to significantly influence safety culture (H1) and safety climate (H2). The effect on safety climate was very strong, with a T-statistic of 12.507 and a P-value of 0.000, underscoring the crucial role of leadership in shaping employees' shared perceptions and understanding of safety practices. This suggests that leaders' consistency and demonstrated commitment are crucial in building a supportive climate and instilling safety values throughout the organization.

However, safety leadership had an indirect effect on safety behavior (H3) and safety performance (H4), as neither hypothesis was statistically significant. This finding suggests that leadership influences indirectly and is mediated through the formation of a safety climate and culture, which in turn influence individual behavior and safety performance. Thus, leadership serves as a fundamental driver, but its direct effect is mediated by other constructs.

Furthermore, the results indicate that safety climate significantly influences safety culture (H5) and safety behavior (H6). This suggests that employee perceptions of a supportive and transparent climate encourage compliance with safety practices and reinforce cultural norms. However, safety climate does not directly influence safety performance (H7). This suggests that its role is more indirect, requiring mediation by safety culture and behavior.

Safety culture emerged as a strong predictor of safety behavior (H8) and safety performance (H9). When safety values are deeply embedded within an organization, employees are more likely to engage in proactive safety behaviors and contribute to improved performance outcomes. Finally, hypothesis H10 suggests that safety behavior directly improves safety performance. This highlights the importance of individual compliance and active participation in safety practices as determinants of overall safety achievement in hydropower plants.

E. INDIRECT INFLUENCE BETWEEN VARIABLES

The results of the indirect effects analysis showed that all paths tested in the model were statistically significant, with p-values below 0.05. This indicates that each indirect relationship contributes significantly to explaining the relationships between constructs in the study. Specifically, safety leadership was found to influence safety behavior through safety climate ($p = 0.007$) and also influence safety performance through safety climate and safety behavior ($p = 0.015$). Similarly, safety leadership indirectly influenced safety performance through safety climate and safety culture ($p = 0.023$).

Furthermore, safety climate demonstrated a significant indirect effect on safety performance through safety culture ($p = 0.015$) and through safety behavior ($p = 0.013$). These findings suggest that although some direct effects were insignificant, the mediating role of safety climate, safety culture, and safety behavior is significant in linking leadership and climate to overall safety performance. In other words, leadership and climate shape the organizational environment, which then drives behavior and culture, ultimately leading to improved safety outcomes.

F. GOODNESS OF FIT

Goodness of Fit (GoF) is a global measure in PLS path modeling that evaluates the overall quality of the measurement (outer) and structural (inner) models. GoF is calculated using the average AVE and R^2 values of the endogenous constructs. In this study, the average AVE was 0.724 and the average R^2 was 0.701, resulting in a GoF value of 0.713. Based on interpretation criteria, this value is considered high ($\text{GoF} > 0.36$), indicating that the model has an excellent fit. This finding confirms that the SEM-PLS model used in this study not only meets the requirements of measurement validity but also shows strong predictive power, making it suitable for comprehensively explaining the relationships between variables.

G. DISCUSSION

The influence between latent variables is examined through path coefficients and their statistical significance levels. Path coefficients represent the

direction and magnitude of the relationship between latent constructs. To assess the robustness of these relationships, bootstrapping is commonly used, producing t-statistics and p-values as indicators of significance. In general, the larger the path coefficient and the more statistically significant the result, the stronger and more reliable the influence of one variable on the other variables in the model.

Evaluating these interrelations is essential for understanding the dynamics between latent constructs and for verifying the hypotheses formulated in the theoretical framework [6]. The following section provides a detailed discussion of the ten hypotheses tested in this study.

1. H1: Safety Leadership → Safety Culture

The results of the hypothesis testing indicate that safety leadership has a positive and significant influence on safety culture, as indicated by a path coefficient of 0.401. Further statistical parameters confirm this relationship, with a t-statistic of 2.712 (>1.96) and a p-value of 0.007 (<0.05). These findings emphasize that leaders who consistently demonstrate concern for safety, provide constructive feedback, and take decisive action on safety-related issues play a crucial role in strengthening safety culture within an organization. These results are consistent with findings concluding that stronger safety leadership correlates with a stronger safety culture [25]. Similarly, other studies have found that safety leadership contributes significantly to the development of a safety culture, particularly through transformational and transactional leadership styles that foster organizational safety values [2]. In the context of a dam maintenance project, this relationship highlights the crucial role of leaders who prioritize safety through personal influence, empowerment, open communication, and active involvement of team members. In the long run, safety leadership is considered one of the most crucial factors in instilling a strong safety culture across organizational practices.

2. H2: Safety Leadership → Safety Climate

The effect of safety leadership on safety climate yielded a path coefficient of 0.789, indicating a very strong positive relationship. With a t-statistic of 12.507 and a p-value of 0.000, this relationship is highly significant. This means that consistent leadership that prioritizes safety, communicates clearly, and empowers employees can create a perceived safe work environment. This finding supports the view that management involvement in workplace safety is a key determinant of a positive safety climate in an organization [24]. Other research indicates that safety leadership plays a significant role in shaping workplace safety perceptions, with communication being the strongest contributing indicator [6,23,18,13].

In dam maintenance projects, effective leadership plays a key role in establishing a positive workplace safety climate. Leaders who demonstrate a strong commitment to safety, model safe behavior, and actively support Standard Operating Procedure programs contribute significantly to improving overall safety

performance, and provide coaching and constructive feedback can improve workers' perceptions of the importance of safety. Furthermore, supervisor involvement, open communication, and attention to risk have been shown to strengthen workers' beliefs that safety is a shared priority. Therefore, an inspirational and participatory leadership approach needs to be prioritized to create a safe, fair and consistent work culture in the project environment.

3. H3: Safety Leadership → Safety Behavior

The results of the H3 hypothesis test indicate that the relationship between safety leadership and safety behavior is not significant, with a path coefficient of 0.139, a t-statistic of 1.339 (<1.96), and a p-value of 0.181 (>0.05). Although the relationship is positive, it is not statistically strong. This indicates that safety leadership does not directly influence worker behavior. Therefore, research conducted on dam maintenance projects yields different results from research that states that safety leadership has a significant impact on safety behavior [23.7]. However, in this study, the relationship may occur through mediating factors such as safety climate or culture.

The analysis results indicate that safety leadership has a significant influence on safety behavior through safety climate, with a p-value of 0.007 (less than 0.05), thus accepting the hypothesis. This indicates that leadership that promotes safety in the workplace plays a significant role in shaping workers' positive perceptions of the safety climate, which ultimately encourages them to behave safely. In the case of a dam maintenance project, a supervisor who begins each morning briefing with an emphasis on safety procedures, wears full safety gear, and actively engages workers in discussions about job risks creates a work climate that demonstrates safety is a priority. Workers who see their supervisor's direct attention and involvement view safety not as a mere formality but as a core workplace value. This encourages them to better adhere to standard operating procedure, alert coworkers, and proactively report potential hazards, thus fostering positive safety behaviors.

Therefore, to improve workplace safety in dam maintenance projects, it is crucial for field leaders or project managers to implement leadership that not only supervises but also inspires, fosters, and creates a work environment that supports safety.

4. H4: Safety Leadership → Safety Performance

The direct effect of safety leadership on safety performance was insignificant, with a path coefficient of 0.100, a t-statistic of 1.124, and a p-value of 0.262. These results indicate that although safety leadership is important, its effect on safety performance is not direct. Instead, factors such as safety behavior and work culture may act as mediating pathways. Therefore, the results of this dam maintenance project study differ from the findings that stated that safety leadership had a direct and significant effect on safety performance [2]. In the context of this study, the influence of leadership on safety performance occurred only indirectly, namely through a mediating role. The analysis results showed

that the effect of safety leadership on safety performance was significant through two mediating pathways:

- a) Through safety climate and safety behavior, with a p-value of 0.015
- b) Through safety climate and safety culture, with a p-value of 0.023

Both values are below the 0.05 threshold, so the hypothesis is accepted. This finding confirms that leadership does not directly result in safety performance, but rather creates a safe work environment and fosters strong safety behaviors and a culture among workers. When a project manager or supervisor actively demonstrates a commitment to safety by efficiently responding to potential hazard reports and involving workers in daily safety assessments, this creates a positive safety climate. In such a climate, workers perceive safety as a genuine concern, not a mere formality. Furthermore, safety behaviors, such as adherence to standard operating procedures when working in high-risk areas (for example, when inspecting dam structures or repairing waterway systems), become more consistent because workers feel supported and valued. In a way, a safety culture begins to take shape, as evidenced by workers' habit of reminding each other, sharing risk experiences, and maintaining a safe work environment even without direct supervision.

Thus, in dam maintenance projects, leadership that fosters a safety climate and culture proves to be a critical foundation for achieving optimal safety performance.

5. H5: Safety Climate → Safety Culture

Hypothesis H5 indicates a positive and significant relationship between Safety Climate and Safety Culture, with a path coefficient of 0.472, a t-statistic of 3.478, and a p-value of 0.001. These results indicate that perceptions of a safe work environment, understood procedures, and consistent managerial actions toward safety foster the strengthening of safety culture values within an organization. Research supporting this finding confirms that a positive safety climate serves as the initial foundation for fostering a sustainable safety culture [24]. This finding is also supported by research that found a positive and significant relationship between safety climate and safety culture. This confirms that positive safety perceptions can strengthen an organization's safety culture [6, 13, 12].

In the context of a dam maintenance project, this can be seen when project management consistently implements safety procedures. These actions create a positive safety climate, where workers view safety as part of the organization's values, not simply an administrative obligation. When this safety climate is consistently implemented, it ultimately forms a strong safety culture. Thus, in a dam maintenance project, a positive safety climate forms the foundation for a safety culture. This relationship is mutually reinforcing when management creates a supportive environment for safety, and workers internalize these values into their daily behavior. This is what makes workplace safety a culture, not just a procedure.

6. H6: Safety Climate → Safety Behavior

Based on the results of the H6 hypothesis test, a path coefficient of 0.424 was obtained, indicating a positive relationship between Safety Climate and Safety Behavior. The t-statistic value of 2.941 (>1.96) indicates that the relationship is statistically significant, while the p-value of 0.003 (<0.05) further confirms the significance of the relationship between the two variables. These results align with findings that a conducive safety climate significantly contributes to improved worker safety behavior [16]. Empirically, this relationship reveals that when a safety climate is characterized by an understanding of procedures, safety measures, and well-developed training programs, it can influence worker behavior to be safer and comply with regulations. Furthermore, factors such as safety communication, early investigation of potential hazards, and prohibition of working in unsafe conditions are elements of the safety climate that mediate the development of safety behavior. This is also supported by research showing that a positive safety climate encourages improved employee safety behavior. A psychological contract approach to safety occurs when workers feel a shared responsibility for maintaining safety thanks to the work culture embedded in the work environment [8,20].

Therefore, building a strong safety climate through concrete and participatory managerial actions is a crucial strategy to encourage safe work behavior, which ultimately contributes to improving overall safety performance in the workplace, particularly in hydropower projects and maintenance.

7. H7: Safety Climate → Safety Performance

The results of the H7 hypothesis test indicate that Safety Climate does not have a significant direct effect on Safety Performance, with a path coefficient of 0.086, a t-statistic of 0.725, and a p-value of 0.469. Although safety climate is important in shaping worker perceptions and attitudes, its influence on safety performance outcomes appears to be indirect. The relationship between safety climate and safety performance can be mediated by the relationship between safety culture and behavior. The indirect relationship between safety climate and safety performance through safety culture has a p-value of 0.015, thus accepting this hypothesis. Furthermore, the relationship between Safety Climate and Safety Performance through Safety Behavior has a p-value of 0.013, thus accepting this hypothesis.

This suggests that safety climate is more likely to influence performance through cultural or behavioral changes, rather than directly. Therefore, interventions to address safety climate need to be accompanied by a structural approach that facilitates behavioral and cultural changes.

8. H8: Safety Culture → Safety Behavior

Hypothesis H8 indicates a significant positive relationship between safety culture and safety behavior, with a path coefficient of 0.347, a t-statistic of 2.183, and a p-value of 0.029. These results indicate that collective

values embedded in the work culture, such as management commitment to safety, employee contribution, and risk awareness, encourage safe behavior. This finding reinforces the idea that a strong safety culture produces individuals who not only comply with procedures but are also actively involved in maintaining safety. This is also supported by research showing that a strong safety culture can encourage better safety behavior [13].

9. H9: Safety Culture → Safety Performance

The analysis shows a positive and significant relationship between safety climate and safety culture. When a safety climate is consistently built with management support, open safety communication, employee involvement, and fair enforcement, these values gradually form a strong and ingrained safety culture. This culture is not simply a habit, but also a shared belief that safety is a shared responsibility. The results show that safety culture has a positive and significant influence on safety performance, with a path coefficient of 0.413, a t-statistic of 2.940, and a p-value of 0.003. This indicates that when a safety culture is well-established, safety performance improves significantly.

In a dam maintenance project, a strong safety culture is evident in field performance. For example, workers wear PPE not only because they are being monitored but also because they believe it is a measure to protect themselves. Another example is when risky findings, such as cracks in water pipes or small landslides in embankments, are immediately reported without fear of repercussions. These findings align with research showing that safety culture contributes significantly to safety performance [1, 12]. A study found that safety culture contributed up to 61.46%, indicating that the values embedded in an organization are the main drivers of safety performance in the field [9]. Therefore, in dam maintenance projects, building a strong safety culture is the first step to driving optimal and sustainable safety performance.

10. H10: Safety Behavior → Safety Performance

Hypothesis H10 indicates that safety behavior has a positive and significant effect on safety performance, with a path coefficient of 0.354, a t-statistic of 2.912, and a p-value of 0.004. This means that the concrete actions of workers in implementing occupational safety principles, such as the use of personal protective equipment, compliance with standard operating procedures, risk awareness, and active participation in activities that follow operating procedures, directly increase the success of the project in achieving the zero accident target, reduce the potential for workplace accidents, and improve safety-based operational efficiency.

A concrete example in a dam maintenance project can be seen when workers carry out spillway cleaning or replacing floodgate components. In wet, slippery, and high risk working conditions, workers who consistently wear complete PPE (helmets, life jackets, and non-slip gloves), inspect equipment before use, and report any

cracks or structural damage to supervisors demonstrate active safety behavior. Even small things, like rearranging electrical cables so they don't obstruct work paths, are preventative behaviors that directly impact workplace safety.

When these behaviors become daily habits in the field, the risk of accidents decreases dramatically, work proceeds smoothly, and productivity increases due to the elimination of lost work time due to workplace accidents. This is the essence of optimal safety performance, which is measured not only by the low number of accidents but also by the discipline and commitment of workers to maintaining safety in every aspect of their work.

Therefore, in dam maintenance projects, strengthening safety behaviors in each individual is a key strategy for achieving superior safety performance.

CONCLUSIONS

This study aims to analyze the relationship between safety leadership, safety climate, safety culture, and safety behavior in influencing safety performance in hydroelectric dam maintenance projects in Sumatra. To achieve this objective, this study used a quantitative approach using the Structural Equation Modeling sem Partial Least Squares (SEM-PLS) method.

The analysis results show that safety leadership has a significant direct influence on safety culture and safety climate, and an indirect influence on safety behavior and performance. The indirect influence of leadership on safety behavior and performance can be mediated by safety climate and culture. Safety climate itself has a direct influence on safety culture and behavior, and an indirect influence on safety performance, mediated by safety culture and behavior. Safety culture has been shown to have a significant direct influence on safety behavior and performance. Finally, safety behavior has a direct influence on performance. Overall, safety culture has the strongest influence on safety performance in hydroelectric dam maintenance projects.

In general, this study confirms that achieving optimal safety performance in hydroelectric dam maintenance projects in the Sumatra region is influenced by the synergy between a strong safety culture, ingrained safety behavior, and supportive leadership and work climate.

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