



Semarak Engineering Journal

Journal homepage:
<https://semarakilmu.my/index.php/sej/index>
ISSN: 3036-0145



Human Factors and Safety Communication in Engineering Safety Performance: A Predictive PLS-SEM Model for Petrochemical Operations

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ARTICLE INFO

Article history:

Received 5 July 2026

Received in revised form 10 September 2026

Accepted 22 September 2026

Available online 5 October 2026

Keywords:

Engineering Safety; Human Factors;
Safety Communication; Safety
Performance; Petrochemical
Operations; PLS-SEM

ABSTRACT

Petrochemical operations are complex engineering systems in which safety performance depends not only on technical safeguards and process controls but also on human and organisational factors that influence how workers perceive, interpret, and respond to safety requirements. Despite advances in engineering controls and occupational safety management systems, incidents continue to occur, highlighting the need to integrate human factors into engineering safety management. This study develops and evaluates a predictive model of engineering safety performance by examining the effects of two culturally embedded human factors, religiosity and fatalism, together with safety communication effectiveness in Malaysian petrochemical operations. A quantitative cross-sectional survey was conducted involving 463 employees and contractors from major petrochemical facilities in Malaysia. Data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The measurement model demonstrated satisfactory reliability and validity. The structural model showed that religiosity significantly influenced safety communication effectiveness ($\beta = 0.442$, $p < 0.001$) and safety performance ($\beta = 0.436$, $p < 0.001$), while fatalism significantly influenced safety communication effectiveness ($\beta = 0.451$, $p < 0.001$) and safety performance ($\beta = 0.378$, $p < 0.001$). In contrast, safety communication effectiveness did not directly predict safety performance ($\beta = -0.006$, $p = 0.954$). The model explained 74.7% of the variance in safety communication effectiveness and 61.2% of the variance in safety performance. These findings demonstrate that engineering safety performance in high-risk petrochemical operations cannot be addressed solely through technical controls and communication systems. Integrating culturally embedded human factors with organisational safety mechanisms provides a more comprehensive approach to engineering safety management and supports the development of human-centred safety interventions for complex industrial operations.

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1. Introduction

Petrochemical facilities are complex socio-technical engineering systems involving hazardous materials, high-pressure and high-temperature processes, interconnected equipment, intensive maintenance activities, and close interaction among operators, engineers, contractors, and management personnel. Failures may result in injuries, fatalities, equipment damage, production interruption, environmental impact, and substantial economic losses. Human-factor analyses of petrochemical fire and explosion events show that violations, inadequate supervision, limitations in human performance, and weak safety culture can interact with technical conditions in accident development [1].

Despite continuous advances in engineering controls and regulatory requirements, incidents continue to occur in high-risk industries. This suggests that engineering safety performance cannot be explained solely by the reliability of physical systems and technical barriers. The effectiveness of engineering controls ultimately depends, in part, on how individuals perceive hazards, interpret safety information, make decisions, comply with procedures, and respond to abnormal operating conditions. Evidence from high-risk industries indicates that communication, human decision-making, supervision and organisational culture can contribute to accidents even when technical safeguards are available [1,2].

This interaction between technical systems and human behaviour is particularly important in petrochemical operations, where employees and contractors work within complex socio-technical environments. Recent evidence from Malaysia's upstream oil and gas sector similarly demonstrates that organisational communication and other safety-culture dimensions significantly contribute to safety performance [15]. Safety communication provides an organisational mechanism for communicating hazards, operating requirements, risk-control measures and lessons learned. Effective communication can improve hazard awareness, support procedural compliance and encourage participation in organisational safety activities. However, communication effectiveness may depend on how safety information is interpreted by individual workers.

Human factors therefore represent an important component of engineering safety management. Workers do not interpret risk and safety information independently of their personal values, beliefs and perceptions. In culturally diverse industrial environments, such factors may affect perceived responsibility, risk perception, preventive behaviour and responses to safety communication. Two factors that are particularly relevant within the Malaysian context are religiosity and fatalism. Religiosity may reinforce personal responsibility, ethical conduct and concern for others, whereas fatalism concerns perceptions regarding fate, external control and the inevitability of events.

Previous occupational safety studies have predominantly examined organisational determinants such as safety climate, leadership, management commitment, training and communication. Comparatively less attention has been given to how culturally embedded human factors interact with organisational safety mechanisms within complex engineering operations. This gap is particularly relevant in the Malaysian petrochemical industry, where technologically sophisticated facilities operate with culturally diverse workforces. Accordingly, a gap remains in understanding how culturally embedded belief systems interact with organisational safety mechanisms in complex engineering operations [3,4].

Therefore, this study develops and evaluates a predictive model of engineering safety performance integrating human factors and safety communication within Malaysian petrochemical operations. Specifically, the study examines the influence of religiosity and fatalism on safety communication effectiveness and safety performance and evaluates whether safety communication effectiveness contributes directly to safety performance. By positioning these relationships within a

socio-technical engineering safety perspective, the study seeks to extend conventional safety management beyond technical and procedural controls towards a more integrated human-centred approach to managing safety in high-risk engineering systems.

2. Literature Review and Hypotheses Development

2.1 Engineering Safety in Petrochemical Operations

Engineering safety in petrochemical operations requires the coordinated management of technical, human and organisational elements. Conventional safety approaches emphasise engineering controls, process safeguards, inspection, maintenance, operating procedures and risk-management systems. However, the performance of these controls is influenced by human interaction with the engineered system. Operators must recognise hazards, correctly interpret information, follow procedures and make appropriate decisions during both normal and abnormal operating conditions.

Accordingly, contemporary engineering safety can be viewed as a socio-technical problem in which technical reliability interacts with human behaviour and organisational processes. This perspective is particularly relevant to petrochemical operations because failures may involve complex interactions among equipment, processes, communication systems and human decisions.

2.2 Human Factors in Engineering Safety Performance

Human factors refer to individual and behavioural characteristics that influence interaction with technical and organisational systems. In safety-critical operations, such factors affect risk perception, procedural compliance, hazard recognition, decision-making and responses to safety information [1,2].

Within culturally diverse workforces, values and belief systems may constitute additional human factors influencing safety behaviour. This study considers religiosity and fatalism as culturally embedded human factors, rather than treating them solely as sociological constructs.

Religiosity may reinforce responsibility, accountability, ethical behaviour and concern for the wellbeing of others. Empirical research has reported a positive relationship between religiosity and workplace safety behaviour, supporting its relevance as a behavioural antecedent [4]. Conversely, fatalism concerns perceived control over events and may affect how workers interpret accident causation and preventive actions. In this study, religiosity was operationalised through responsibility, ethical behaviour and accountability, while fatalism captured destiny, inevitability, external control and beliefs concerning accident causation.

2.3 Safety Communication as an Organisational Safety Mechanism

Safety communication connects engineering requirements and organisational safety systems with workforce behaviour. It includes the clarity and timeliness of information, feedback mechanisms, communication openness and management communication practices. Prior research in the Malaysian petrochemical industry has shown that safety communication can operate as an important mechanism linking safety culture with safety performance [3].

Within petrochemical operations, effective safety communication is particularly important because engineers, operators, technicians, contractors and management personnel must coordinate activities involving complex hazards and operating conditions. Communication therefore acts as an interface between engineering safety requirements and human action.

However, providing safety information does not necessarily guarantee appropriate safety behaviour. Workers may interpret identical information differently depending on their beliefs, perceptions of control, experience and cultural orientation. Thus, safety communication should be considered alongside underlying human factors when evaluating engineering safety performance.

2.4 Integrated Human – Organisational Engineering Safety Framework

Fatalism refers to the belief that life events are predetermined by fate, destiny, luck, or external forces beyond individual control. Individuals exhibiting strong fatalistic orientations often perceive outcomes as inevitable and may believe that personal actions have limited influence over future events.

Within behavioural science, fatalism is frequently associated with reduced perceptions of control, lower self-efficacy, diminished motivation, and weaker intentions to engage in preventive behaviours. The Theory of Planned Behaviour suggests that individuals who perceive limited control over outcomes are less likely to undertake actions intended to influence those outcomes.

In occupational safety contexts, fatalistic beliefs may discourage proactive safety behaviour by reducing workers' motivation to identify hazards, report unsafe conditions, or comply with preventive measures. Employees who believe accidents are unavoidable may perceive safety programmes as less meaningful and may therefore engage less actively in organisational safety initiatives.

Previous studies have generally reported negative relationships between fatalism and safety-related outcomes [16,17]. Fatalistic attitudes have been associated with reduced compliance, lower risk perception, weaker safety participation, and increased engagement in risky behaviours. Nevertheless, findings remain inconsistent across cultural settings. In some societies, fatalistic beliefs coexist with strong religious values and may not necessarily undermine preventive actions.

This complexity is particularly relevant within multicultural environments such as Malaysia, where concepts of destiny, divine will, and personal responsibility may interact in unique ways. Therefore, empirical examination of fatalism within the Malaysian petrochemical industry is necessary to better understand its influence on safety communication and safety performance.

2.5 Theoretical Foundation

This study integrates several complementary theoretical perspectives to explain the relationships among religiosity, fatalism, safety communication effectiveness, and safety performance.

Theory of Planned Behaviour (TPB)

The Theory of Planned Behaviour (TPB) proposes that behaviour is influenced by attitudes, subjective norms and perceived behavioural control [5]. In the present engineering-safety context, religiosity may reinforce value-based attitudes and normative responsibility, whereas fatalistic interpretations may influence perceived behavioural control and beliefs about the preventability of adverse events.

Protection Motivation Theory (PMT)

Protection Motivation Theory (PMT) explains protective behaviour through two cognitive processes: threat appraisal and coping appraisal. Threat appraisal involves an individual's assessment

of the severity of a hazard and perceived vulnerability to its consequences, whereas coping appraisal considers response efficacy and self-efficacy [6]. In petrochemical operations, effective safety communication may strengthen workers' awareness of process hazards and confidence in preventive measures, while culturally embedded factors such as religiosity and fatalism may influence perceptions of risk, personal responsibility, control, and the effectiveness of preventive action. PMT therefore provides a relevant theoretical basis for explaining how individual beliefs and safety communication may influence protective safety behaviour and safety performance.

Social Cognitive Theory (SCT)

Social Cognitive Theory emphasises reciprocal interactions among personal beliefs, environmental influences and behaviour [7]. Safety communication represents an organisational/environmental influence, whereas religiosity and fatalism represent personal cognitive factors that may shape behavioural outcomes.

High Reliability Organisation (HRO) Theory

High Reliability Organisation (HRO) scholarship highlights operational mindfulness, learning, sensitivity to operations, resilience and deference to expertise as foundations of reliable performance in hazardous environments [8,9]. Effective communication supports these processes by facilitating information sharing, early hazard detection and coordinated responses to emerging risks.

Together, these theories provide a comprehensive framework for understanding how belief systems and communication processes influence safety performance within complex industrial environments.

Table 1
Constructs and engineering-safety interpretation

Construct	Role in model	Operational emphasis	Engineering-safety interpretation
Religiosity	Exogenous human factor	Responsibility, ethical behaviour, accountability	May shape moral responsibility, self-regulation and concern for co-workers.
Fatalism	Exogenous human factor	Destiny, inevitability, external control, accident causation	May shape perceived control, risk interpretation and beliefs about preventability.
Safety Communication Effectiveness	Endogenous organisational mechanism	Clarity, timeliness, feedback, openness, management communication	Translates hazards, controls and operating requirements into shared understanding.

Safety Performance	Principal outcome	Safety compliance, participation and safe work behaviour	Reflects behavioural execution of engineering and organisational safety controls.
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2.6 Hypotheses Development

H1: Effect of Religiosity on Safety Communication Effectiveness

Religiosity may influence the way employees respond to safety information at work. Values associated with personal responsibility, accountability and concern for others can encourage workers to pay closer attention to safety instructions and participate more openly in safety-related communication. In petrochemical operations, where safe work depends on workers understanding and responding to information about hazards and controls, these values may contribute to more effective safety communication. H1: Religiosity has a positive influence on safety communication effectiveness.

H2: Effect of Religiosity on Safety Performance

Religious values may also shape how workers approach their safety responsibilities. A strong sense of accountability and concern for the wellbeing of others may encourage workers to follow procedures, avoid unnecessary risks and take part in safety activities. Such behaviour is particularly relevant in petrochemical operations, where individual actions can affect not only the worker concerned but also co-workers and the wider operation. H2: Religiosity has a positive influence on safety performance.

H3: Effect of Fatalism on Safety Communication Effectiveness

Fatalism reflects the extent to which individuals believe that events are determined by fate or forces beyond their personal control. Such beliefs may influence how workers interpret information about hazards, accident prevention and the effectiveness of safety controls. In the Malaysian petrochemical work environment, fatalistic beliefs may therefore affect how safety messages are understood and acted upon. H3: Fatalism significantly influences safety communication effectiveness.

H4: Effect of Fatalism on Safety Performance

Workers' beliefs about fate and personal control may also influence their safety behaviour. When an individual views an accident as unavoidable or beyond personal control, this perception may affect decisions about following procedures, responding to hazards or taking preventive action. Fatalism is therefore expected to have a meaningful relationship with safety performance. H4: Fatalism significantly influences safety performance.

H5: Effect of Safety Communication Effectiveness on Safety Performance

Safety communication is important in ensuring that workers understand hazards, operating requirements and the controls needed to perform their work safely. Clear and timely information, together with opportunities for feedback, can help workers make better safety decisions and follow established procedures. Effective communication is therefore expected to support safer work practices and better safety performance. H5: Safety communication effectiveness has a positive influence on safety performance.

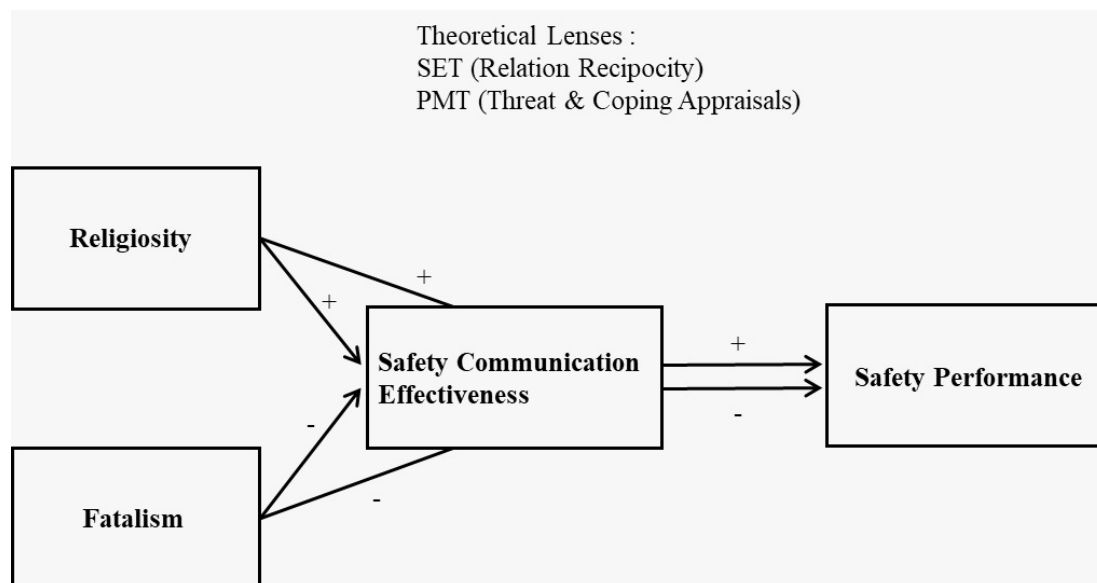


Fig. 1. Conceptual model linking culturally embedded human factors, safety communication effectiveness and safety performance

3. Methodology

3.1 Research Design

This study employed a quantitative cross-sectional research design to develop and evaluate a predictive model of engineering safety performance in Malaysian petrochemical operations. The model examined the relationships between culturally embedded human factors, represented by religiosity and fatalism, safety communication effectiveness, and safety performance.

A positivist research paradigm was adopted because the constructs were operationalised as measurable latent variables and their hypothesised relationships were evaluated statistically. The cross-sectional design enabled data to be collected from a geographically dispersed petrochemical workforce and supported multivariate analysis using Partial Least Squares Structural Equation Modelling (PLS-SEM).

3.2 Research Framework

The proposed model conceptualised religiosity and fatalism as exogenous human-factor constructs, safety communication effectiveness as an endogenous organisational construct, and safety performance as the principal safety outcome. The model examined five relationships: the influence of religiosity on safety communication effectiveness; the influence of religiosity on safety performance; the influence of fatalism on safety communication effectiveness; the influence of fatalism on safety performance; and the influence of safety communication effectiveness on safety performance.

3.3 Population and Sampling

The target population comprised employees and contractors working in Malaysian petrochemical facilities, including management personnel, engineers, supervisors, technicians, operators, maintenance personnel, safety professionals and support staff. A stratified random sampling

approach was employed to provide representation across organisational levels and occupational categories.

Respondents were recruited from petrochemical facilities associated with major Malaysian industrial hubs, including Kertih, Gebeng, Pengerang, Bintulu and Sipitang. A total of 463 valid responses were included in the analysis.

3.4 Measurement Instrument

Data were collected using a structured questionnaire comprising five sections: demographic characteristics, religiosity, fatalism, safety communication effectiveness and safety performance.

Religiosity assessed religious commitment and values associated with responsibility, ethical behaviour and accountability. Fatalism assessed perceptions of destiny, inevitability, external control and accident causation. Safety communication effectiveness covered communication clarity, timeliness, feedback, openness and management communication. Safety performance assessed safety compliance, safety participation, safe work behaviour and safety-related organisational performance, consistent with established safety-performance conceptualisations [13,14].

All constructs were measured using a five-point Likert scale ranging from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*), using measurement items adapted from previous studies.

3.5 Data Collection Procedure

Self-administered questionnaires were distributed to employees and contractors within the participating petrochemical facilities. Participation was voluntary, confidentiality and anonymity were maintained, and ethical approval was obtained before data collection.

3.6 Data Analysis

Preliminary analysis included missing-data assessment, descriptive statistics, normality assessment and multicollinearity testing. SPSS was used for descriptive analysis.

The hypothesised model was evaluated using PLS-SEM with SmartPLS because the analysis involved multiple latent constructs and was prediction-oriented [10]. Measurement-model assessment included indicator reliability, Cronbach's alpha, composite reliability, average variance extracted (AVE), the Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT) [10,11].

The structural model was evaluated using path coefficients, bootstrapping with **5,000 resamples**, coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2) and model-fit indicators.

4. Results

4.1 Respondent Profile

A total of 463 valid responses from employees and contractors working in Malaysian petrochemical facilities were included in the analysis. The respondents represented different organisational levels and occupational functions, including management personnel, engineers, supervisors, technicians, operators, maintenance personnel, safety professionals, and support staff. This workforce composition reflects the multidisciplinary nature of petrochemical operations, where engineering safety depends on coordinated interactions among technical, operational, maintenance, and organisational functions.

The respondents also represented diverse demographic and cultural backgrounds. Such diversity is particularly relevant to the present study because the proposed model examines religiosity and fatalism as culturally embedded human factors that may influence workers' interpretation of safety communication and their safety-related behaviour.

4.2 Measurement Model Assessment

The measurement model was evaluated before testing the structural relationships. Indicator reliability, internal consistency reliability, convergent validity, and discriminant validity were assessed using established PLS-SEM criteria.

The measurement items demonstrated satisfactory indicator reliability, with outer loadings ranging from 0.780 to 0.944 for Fatalism, 0.840 to 0.902 for Religiosity, 0.797 to 0.893 for Safety Communication Effectiveness, and 0.930 to 0.944 for Safety Performance. Internal consistency was strong: Cronbach's alpha ranged from 0.946 to 0.966 and composite reliability (rhoC) ranged from 0.955 to 0.973. Convergent validity was established because all AVE values exceeded 0.50 (0.796, 0.765, 0.727 and 0.879, respectively), as summarised in Table 2.

Discriminant validity was examined using the Fornell-Larcker criterion and the Heterotrait-Monotrait ratio (HTMT). The HTMT values ranged from 0.699 to 0.890 and therefore remained below the commonly accepted upper limit of 0.90, supporting empirical distinctiveness among the four constructs (Table 3). The Fornell-Larcker criterion was also satisfied in the thesis measurement model.

Collectively, these results confirmed that the measurement model provided sufficient reliability and validity for evaluating the hypothesised relationships.

Table 2
Measurement model reliability and convergent validity

Construct	Items	Outer loading range	Cronbach's α	ρ_A	ρ_C	AVE
Fatalism	7	0.780–0.944	0.956	0.959	0.964	0.796
Religiosity	10	0.840–0.902	0.966	0.966	0.97	0.765
Safety Communication Effectiveness	8	0.797–0.893	0.946	0.95	0.955	0.727
Safety Performance	5	0.930–0.944	0.966	0.966	0.973	0.879

Table 3
Discriminant validity assessment (HTMT)

Construct	Fatalism	Religiosity	Safety Communication Effectiveness
Fatalism	—		
Religiosity	0.89	—	
Safety Communication Effectiveness	0.885	0.87	—
Safety Performance	0.78	0.786	0.699

4.3 Structural Model Assessment

The structural model was evaluated using path coefficients, bootstrapping with 5,000 resamples, coefficients of determination (R^2), effect sizes, and predictive relevance indicators.

The model demonstrated substantial explanatory capability for the endogenous constructs. Religiosity and fatalism jointly explained 74.7% of the variance in Safety Communication Effectiveness ($R^2 = 0.747$). The model also explained 61.2% of the variance in Safety Performance ($R^2 = 0.612$) (Table 4).

These values indicate that the culturally embedded human factors included in the model account for considerable variation in workers' perceptions of safety communication and safety performance within petrochemical operations.

Table 4

Explanatory power of the structural model

Endogenous construct	R^2	Interpretation
Safety Communication Effectiveness	0.747	Substantial explanatory power
Safety Performance	0.612	Moderate-to-substantial explanatory power

4.4 Hypothesis Testing

The structural-path results revealed significant relationships between the culturally embedded human factors and the two safety-related outcomes. The complete hypothesis-testing results are summarised in Table 5.

Religiosity had a significant positive effect on Safety Communication Effectiveness ($\beta = 0.442$, $p < 0.001$). Religiosity also demonstrated a significant positive relationship with Safety Performance ($\beta = 0.436$, $p < 0.001$). These findings indicate that stronger religiosity was associated with more favourable perceptions of organisational safety communication and higher reported safety performance.

Fatalism also demonstrated a significant positive effect on Safety Communication Effectiveness ($\beta = 0.451$, $p < 0.001$) and Safety Performance ($\beta = 0.378$, $p < 0.001$). Although fatalism is frequently associated theoretically with reduced perceptions of individual control, the positive relationships observed in the present study suggest a more complex interpretation within the Malaysian petrochemical context.

In contrast, Safety Communication Effectiveness did not significantly predict Safety Performance ($\beta = -0.006$, $p = 0.954$). The magnitude of the coefficient was effectively zero, indicating that favourable perceptions of safety communication alone did not translate directly into improved safety performance within the proposed model.

4.5 Summary of Hypothesis Testing

The results therefore demonstrate that religiosity and fatalism have direct relationships with both safety communication effectiveness and safety performance, whereas safety communication effectiveness itself does not demonstrate a statistically significant direct relationship with safety performance.

Table 5
Structural model and hypothesis testing results

Hypothesis	Structural Relationship	β	p-value	Decision
H1	Effect of Religiosity on Safety Communication Effectiveness	0.442	<0.001	Supported
H2	Effect of Religiosity on Safety Performance	0.436	<0.001	Supported
H3	Effect of Fatalism on Safety Communication Effectiveness	0.451	<0.001	Supported
H4	Effect of Fatalism on Safety Performance	0.378	<0.001	Supported
H5	Effect of Safety Communication Effectiveness on Safety Performance	-0.006	0.954	Not supported

5. Discussion

5.1 Culturally Embedded Human Factors in Engineering Safety

The findings demonstrate that engineering safety performance in complex petrochemical operations is influenced by the interaction of engineering controls, organisational systems, communication processes and human factors. Within this broader engineering context, the Safety Performance construct examined in this study represents the behavioural dimension through which workers interact with technical and organisational safety controls.

The significant relationships identified for religiosity and fatalism indicate that culturally embedded beliefs may influence how workers perceive responsibility, control, risk, and preventive action. These beliefs can consequently affect how workers interpret safety information and interact with organisational and engineering safety controls.

The findings therefore support a socio-technical interpretation of engineering safety in which workers should not be regarded merely as recipients of procedures or safety information. They actively interpret safety requirements through individual psychological, cultural, and behavioural frameworks.

5.2 Religiosity and Safety Communication Effectiveness

Religiosity demonstrated a significant positive relationship with Safety Communication Effectiveness ($\beta = 0.442$, $p < 0.001$). This suggests that workers with stronger religious orientation may perceive safety communication more positively or engage more meaningfully with organisational safety messages.

One possible explanation concerns the internalisation of responsibility and accountability. Religiosity may reinforce values associated with ethical conduct, responsibility toward others, self-discipline, and avoidance of preventable harm. Consequently, safety messages concerning hazard prevention, procedural compliance, and protection of co-workers may be interpreted not only as organisational instructions but also as responsibilities consistent with workers' underlying value systems.

In petrochemical operations, this mechanism can be important during toolbox meetings, permit-to-work briefings, shift handovers, emergency communication, and discussions of operational hazards. A technically accurate message may achieve greater behavioural relevance when workers connect it with an internal sense of responsibility.

From an engineering-management perspective, this does not imply that safety communication should become explicitly religious. Instead, communication can emphasise culturally inclusive values such as responsibility, accountability, care for colleagues, stewardship, and prevention of harm.

5.3 Religiosity and Safety Performance

Religiosity also demonstrated a significant positive relationship with Safety Performance ($\beta = 0.436$, $p < 0.001$). This finding indicates that religiosity may operate beyond workers' perceptions of communication and directly influence safety-related behaviour.

Several behavioural mechanisms may explain this relationship. Religiosity may strengthen self-regulation, moral responsibility, conscientious behaviour, and concern for the wellbeing of others. Within safety-critical engineering operations, these mechanisms may encourage workers to follow procedures even when direct supervision is absent.

For example, an operator performing equipment isolation may regard proper verification not simply as procedural compliance but as a responsibility to ensure that maintenance personnel are not exposed to uncontrolled energy. Similarly, a worker observing an unsafe lifting operation may perceive intervention as a responsibility toward colleagues rather than merely an organisational requirement.

This interpretation is consistent with the broader principle that effective engineering barriers require reliable human execution. Procedures such as lock-out/tag-out, confined-space entry, gas testing, lifting controls, and permit-to-work verification depend upon workers consistently performing the required actions.

Religiosity may therefore function as an internal motivational factor that reinforces the human implementation of engineering safety controls.

5.4 Fatalism and Safety Communication Effectiveness

Fatalism demonstrated the strongest relationship with Safety Communication Effectiveness among the tested structural paths ($\beta = 0.451$, $p < 0.001$). This finding is noteworthy because fatalism is often assumed to undermine preventive safety behaviour by encouraging perceptions that accidents are predetermined or beyond individual control.

The present results suggest that the relationship may be more complex within the Malaysian petrochemical context.

One possible explanation is that fatalistic beliefs do not necessarily represent helplessness. Workers may acknowledge uncertainty, destiny, or factors beyond complete human control while simultaneously accepting responsibility for taking appropriate preventive action.

This distinction can be conceptualised as the difference between passive fatalism and responsibility-compatible fatalism.

Passive fatalism implies that preventive action has little value because outcomes are predetermined. In contrast, responsibility-compatible fatalism acknowledges that complete control over outcomes is impossible while maintaining that individuals remain responsible for exercising appropriate precautions.

The latter interpretation could coexist with strong engagement in safety communication. Workers may recognise uncertainty while still valuing toolbox discussions, hazard information, operating instructions, and preventive controls as appropriate actions that must be undertaken.

This distinction is particularly important when interpreting culturally embedded beliefs within Malaysian workplaces. Fatalism should therefore not automatically be equated with unsafe behaviour without considering how workers understand personal responsibility and preventive action.

5.5 Fatalism and Safety Performance

Fatalism also had a significant positive relationship with Safety Performance ($\beta = 0.378$, $p < 0.001$). This finding differs from the conventional assumption that fatalistic beliefs necessarily reduce safety behaviour.

A possible explanation is that acknowledgement of uncertainty may increase caution rather than reduce it among some workers. Petrochemical employees routinely encounter hazards that cannot be completely eliminated, including flammable materials, toxic substances, high-pressure systems, rotating equipment, confined spaces, and major process hazards. Recognition that complete control is impossible may reinforce respect for these hazards and encourage adherence to preventive measures.

However, this interpretation should be made cautiously. The cross-sectional PLS-SEM results establish statistical relationships but do not demonstrate the specific psychological mechanism responsible for those relationships.

The finding nevertheless suggests that future safety research should distinguish between different dimensions of fatalism, particularly beliefs reflecting external control, acceptance of uncertainty, behavioural helplessness, and responsibility despite uncertainty.

This distinction represents an important theoretical opportunity for engineering safety research in culturally diverse industrial environments.

5.6 Why Safety Communication Effectiveness Did Not Directly Predict Safety Performance

One of the most important findings is the non-significant relationship between Safety Communication Effectiveness and Safety Performance ($\beta = -0.006$, $p = 0.954$). This contrasts with studies reporting positive or mediating effects of safety communication on safety outcomes [3,12], indicating that communication-performance relationships may be contingent on the wider socio-technical and behavioural context.

This result indicates that perceiving safety communication as clear, timely, open, and effective does not necessarily translate directly into safer behaviour.

From a human-factors perspective, effective safety communication involves more than simply delivering a safety message. Workers must first understand the information, accept its relevance, internalise its importance, make an appropriate decision, and ultimately translate that decision into safe action.

A communication system may function successfully at the first two stages while failing to influence actual behaviour.

For example, workers may understand a toolbox briefing but subsequently bypass a requirement because of production pressure, time constraints, supervisory expectations, contractor practices, normalisation of deviations, perceived inconvenience, or insufficient authority to intervene.

This distinction is particularly relevant in petrochemical engineering operations. A worker can understand the requirement for gas testing before confined-space entry but still enter prematurely. Similarly, personnel may understand lifting restrictions but proceed because of schedule pressure. Communication quality alone cannot eliminate these competing behavioural and organisational influences.

The result therefore should not be interpreted as evidence that safety communication is unimportant. Rather, it indicates that communication may be a necessary enabling condition whose behavioural effectiveness depends on the wider socio-technical environment.

5.7 Engineering Interpretation of the Findings

The findings support an integrated human, organisational perspective of engineering safety. In petrochemical operations, safety performance develops through the interaction of several interconnected elements. Engineering design and inherent safety principles provide the foundation for engineered safeguards, which are supported by operating and maintenance procedures and wider organisational controls. Safety communication helps workers understand these requirements and controls, while human interpretation and decision-making determine how the information is translated into safe behaviour. Together, these technical, organisational and human elements contribute to overall safety performance.

Failures can occur at the interface between these layers.

For example, an engineering isolation system may be technically adequate, but its effectiveness can be compromised if personnel misunderstand the isolation boundary, deliberately bypass the procedure, fail to communicate changes, or perceive intervention as unnecessary.

Conversely, competent and safety-conscious personnel can strengthen the system by identifying deviations, reporting abnormal conditions, exercising Stop Work Authority, and ensuring that engineering safeguards are correctly implemented.

Religiosity and fatalism may therefore be conceptualised as latent human factors influencing workers' interaction with engineered and organisational safety barriers rather than as independent substitutes for technical safety controls.

5.8 Implications for Malaysian Petrochemical Operations

The findings have several implications for petrochemical operators, engineering contractors, and safety managers.

First, safety communication should move beyond information transmission toward behavioural verification. Toolbox meetings, permit briefings, and safety instructions should verify whether workers understand the hazard, accept the importance of the control, perceive themselves as capable of intervening, and intend to perform the required action.

Second, safety communication should reinforce individual agency. Messages should clearly communicate that incidents are preventable and that individual actions can interrupt accident sequences.

For example, communication surrounding Stop Work Authority should emphasise that identifying an unsafe condition creates both the authority and responsibility to intervene, regardless of organisational hierarchy.

Third, culturally sensitive communication can emphasise universal values such as responsibility, protection of colleagues, accountability, prevention of harm, and collective wellbeing without promoting any particular religion.

Fourth, contractor management deserves particular attention. Contractors may operate under different organisational cultures, employment conditions, supervisory arrangements, and behavioural norms. Engineering safety programmes should therefore verify behavioural understanding across contractor interfaces rather than assuming that distribution of identical safety information produces identical responses.

Finally, the non-significant communication-performance relationship suggests that organisations should not rely exclusively on communication-frequency indicators, such as the number of toolbox meetings or safety briefings. Effectiveness should also be evaluated through behavioural and operational indicators, including hazard reporting, Stop Work interventions, permit compliance, procedural adherence, closure of corrective actions, and management response to reported concerns.

5.9 Theoretical Contribution

This study contributes to engineering safety research by demonstrating how culturally embedded human factors are associated with the behavioural dimension of engineering safety performance in complex petrochemical operations.

The findings suggest that technical and organisational safety systems operate within a broader behavioural context. Workers may interpret hazards and preventive controls differently depending on their perceptions of responsibility, personal control, accident causation, and potential consequences.

The findings also show that effective safety communication alone does not necessarily result in improved safety performance. Although clear and timely communication is important, its influence on safety performance may depend on how workers understand the information, perceive their responsibility, and translate safety requirements into actual behaviour.

Instead, the findings suggest a more complex socio-technical relationship in which human factors can exert substantial direct influences on both the perception of communication and safety performance.

The positive fatalism relationships are particularly noteworthy because they indicate that fatalistic beliefs should not automatically be interpreted as behavioural helplessness. The meaning and behavioural consequences of fatalism may depend on its cultural context and its interaction with perceived personal responsibility.

5.10 Practical Engineering Safety Framework

Based on the findings, engineering safety management in petrochemical operations can be conceptualised through four interacting dimensions:

Technical Controls: inherently safer design, process safeguards, isolation systems, alarms, inspection, maintenance, and engineering barriers.

Organisational Controls: procedures, permit-to-work systems, supervision, competency management, contractor management, and safety governance.

Communication Mechanisms: toolbox meetings, shift handovers, risk communication, emergency communication, feedback systems, and management communication.

Human Factors: beliefs regarding responsibility, accountability, controllability, risk, preventive action, and culturally embedded interpretations represented in this study by religiosity and fatalism.

Effective safety performance emerges from the interaction among these dimensions rather than from any single component operating independently.

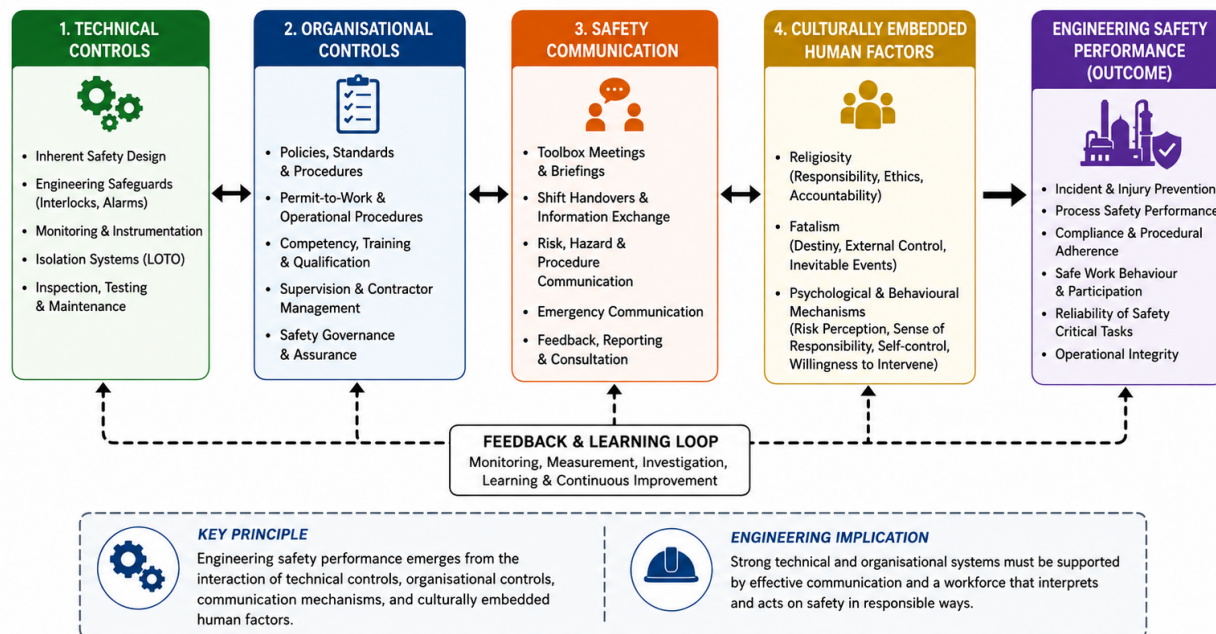


Fig. 2. Integrated socio-technical framework for engineering safety performance in Malaysian petrochemical operations

6. Conclusion

6.1 Conclusion

This study examined how culturally embedded human factors and safety communication effectiveness contribute to the behavioural dimension of engineering safety performance within Malaysian petrochemical operations.

The results demonstrated that religiosity significantly influenced Safety Communication Effectiveness ($\beta = 0.442$, $p < 0.001$) and Safety Performance ($\beta = 0.436$, $p < 0.001$). Fatalism also significantly influenced Safety Communication Effectiveness ($\beta = 0.451$, $p < 0.001$) and Safety Performance ($\beta = 0.378$, $p < 0.001$). In contrast, Safety Communication Effectiveness did not demonstrate a significant direct relationship with Safety Performance ($\beta = -0.006$, $p = 0.954$).

The model explained 74.7% of the variance in Safety Communication Effectiveness and 61.2% of the variance in Safety Performance, demonstrating substantial explanatory capability for the proposed human – organisational safety framework.

The findings demonstrate that safety performance in complex petrochemical engineering operations cannot be understood solely through the presence of technical controls or the effectiveness of organisational safety communication. Workers interpret safety requirements

through culturally embedded beliefs concerning responsibility, control, causation, and preventive action. These interpretations can influence how personnel interact with engineering safeguards, operating procedures, and organisational safety systems.

The positive influence of religiosity may reflect mechanisms involving moral responsibility, accountability, self-regulation, and concern for others. The positive relationships involving fatalism suggest that fatalistic beliefs within the Malaysian context should not automatically be interpreted as behavioural passivity. Acceptance of uncertainty or fate may coexist with responsibility for preventive action.

Most importantly, the non-significant relationship between Safety Communication Effectiveness and Safety Performance indicates that communication alone is insufficient to guarantee safe behaviour. Safety information must be understood, accepted, internalised, and translated into appropriate operational action within a supportive engineering and organisational environment.

6.2 Practical Implications

Petrochemical organisations should integrate human-factor considerations into existing engineering safety management rather than treating them as substitutes for technical controls.

Safety programmes should reinforce personal responsibility, perceived control, preventive action, and willingness to intervene. Toolbox meetings, permit-to-work briefings, shift handovers, and safety leadership interactions should therefore evaluate behavioural understanding rather than merely confirm that communication has occurred.

Organisations should also strengthen mechanisms that allow employees and contractors to convert safety information into action, particularly Stop Work Authority, hazard reporting, near-miss reporting, procedural compliance, and escalation of abnormal operating conditions.

Culturally responsive safety communication should focus on inclusive values such as accountability, care for colleagues, prevention of harm, and collective responsibility while respecting the multicultural and multi-faith characteristics of the Malaysian workforce.

6.3 Limitations

Several limitations should be acknowledged. First, the cross-sectional design limits causal interpretation of the relationships identified in the structural model. Second, the study relied on self-reported questionnaire data, which may be affected by common-method and social-desirability influences. Third, the study was conducted within Malaysian petrochemical operations; consequently, the findings should be generalised cautiously to other national, cultural, and industrial contexts.

In addition, religiosity and fatalism are multidimensional constructs. The quantitative model identifies relationships among the constructs but cannot fully explain the psychological mechanisms responsible for those relationships.

6.4 Future Research

Future research should examine the identified relationships longitudinally and across different high-risk engineering sectors, including oil and gas, chemical processing, power generation, construction, transportation, and major infrastructure.

Further studies should distinguish passive fatalism from responsibility-compatible or culturally contextualised fatalism to determine whether these dimensions produce different safety outcomes.

Qualitative interviews or mixed-method studies could also investigate how workers interpret fate, responsibility, accident preventability, and safety intervention in actual operational situations.

Future models may additionally incorporate engineering and organisational variables such as safety climate, leadership, production pressure, contractor management, perceived behavioural control, risk perception, Stop Work Authority, and process safety culture.

6.5 Final Engineering Safety Perspective

The principal implication of this study is that engineering safety is simultaneously a technical, organisational, and human problem.

Engineering controls determine what protection is available. Organisational systems determine how that protection is managed. Safety communication determines how requirements are transmitted and understood. Human factors influence whether those requirements are ultimately translated into safe operational behaviour.

Accordingly, improving safety performance in complex petrochemical operations requires not only technically reliable barriers but also a workforce that perceives responsibility, control, and preventive action in ways that reinforce those barriers. Integrating culturally embedded human factors into engineering safety management therefore provides a more comprehensive approach to understanding and strengthening safety performance in multicultural, high-risk industrial environments.

Acknowledgement

The author acknowledges the Fundamental Research Grant Scheme (FRGS), grant number FRGS/1/2024/SKK06/UTM/02/4 funded by the Ministry of Higher Education (MOHE), Malaysia, and the part of this research is supported by the GUP, grant number PY/2024/01673, UTM Fundamental Research Grant Universiti Teknologi Malaysia.

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