UNIVERSITI TEKNOLOGI MARA

DEVELOPMENT AND EVALUATION OF THE BEHAVIOURAL OCCUPATIONAL SAFETY CULTURE APPLICATION (BOSCA) BASED ON PSYCHOLOGICAL, BEHAVIOURAL AND SITUATIONAL SAFETY CULTURE DIMENSIONS FOR THE MALAYSIAN OIL AND GAS INDUSTRY

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PhD

July 2026

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Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Environmental Health and Safety)

Faculty of Health Sciences

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CONFIRMATION BY PANEL OF EXAMINERS

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ABSTRACT

This research examined the fundamental dimensions of safety culture and translated them into the design, development, and evaluation of a proactive mobile application framework for the Malaysian oil and gas industry. Despite stringent legislative requirements including the Occupational Safety and Health (Amendment) Act 2022 and sector-specific regulations, accident rates within the industry have remained persistently high, indicating that compliance-focused strategies alone are insufficient to achieve sustained improvements in safety performance. Prior studies highlighted that unsafe acts, unsafe behaviours, and weak organisational safety cultures were major contributors to workplace incidents, yet only limited efforts had been spent integrating behavioural, psychological, and situational factors into a unified, technology-enabled intervention. This gap signalled the need for a digital, user-centred solution capable of enhancing proactive safety engagement in real time. The study was conducted in three sequential phases. In Phase One, the key elements of safety culture were identified and refined through a comprehensive literature review and evidence synthesis, categorising them into three core dimensions: psychological, behavioural, and situational. In Phase Two, a mobile application framework was designed and developed based on these dimensions, guided by Cooper's Reciprocal Safety Culture Model, Hudson's Safety Culture Maturity Model, and instructional design principles to ensure pedagogical logic, usability, and contextual relevance. The resulting application incorporated safety training, incident reporting, hazard identification, communication tools, and embedded behavioural reinforcements to enhance proactive safety actions. In Phase Three, the application was evaluated by industry practitioners to assess user acceptance, perceived usefulness, and intention to use. The findings identified three principal safety culture dimensions, namely psychological, behavioural, and situational. AHP analysis revealed that the behavioural dimension was the most preferred category among stakeholders, followed by situational and psychological dimensions. Within the behavioural category, safety rules, safety ownership, and safety communication emerged as the highest-ranked elements. SEM analysis further confirmed that the behavioural construct demonstrated the strongest contribution to safety culture compared to the other dimensions. The developed BOSCA application was subsequently validated by experts, with all evaluation items meeting the Fuzzy Delphi acceptance criteria (threshold value $d \leq 0.2$, expert agreement $\geq 75\%$, and α-cut ≥ 0.5). User acceptance evaluation indicated positive levels of perceived usefulness, usability, and intention to use the application, supporting its suitability as a digital intervention for strengthening proactive safety culture practices in the Malaysian oil and gas industry. Overall, the study contributed to theoretical advancement by integrating safety culture determinants into a holistic digital framework and provided practical value through the creation of a culturally adapted, self-directed mobile application. The framework offers guidance for future development of digital safety tools and supports the broader goal of fostering a sustainable, technology-enabled safety culture in high-risk industries such as oil and gas in Malaysia.

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LIST OF SYMBOLS

Symbols

A	Number of Latent Variables or Components in the Model
a	Index of a Component or Latent Variable
b	Regression Coefficient in the Model
$e_1 - e_n$	Measurement Error Terms Associated with Observed Indicators in SEM
K	Total Number of Blocks or Latent Variable Groups in the Model
N	Total Number of Experts or Respondents in the Analysis
Σ	Pooled Covariance Matrix for the Two Classes
Σ^g	Covariance Matrix for Class *g*

LIST OF ABBREVIATIONS

Abbreviations

AHP	Analytical Hierarchy Process
BOSCA	Behavioural Occupational Safety Culture Application
CVI	Content Validation Index
CVR	Content Validation Ratio
DOSM	Department Of Statistics Malaysia
OGSE	Oil & Gas Services and Equipment
PWA	Progressive Web Application
SCM	Swiss Cheese Model
SCQ	Safety Culture Questionnaire
SEM	Structure Equation Modelling
UTAUT	Unified Theory of Acceptance and Use of Technology

LIST OF NOMENCLATURES

Nomenclatures

AVE	Average Variance Extracted, No Unit
β	Standardised Regression Coefficient, No Unit
CR	Composite Reliability, No Unit
N	Total Number of Subjects, No Unit
n_e	Number of Subject Matter Experts, No Unit
p	Probability Value Indicating Statistical Significance, No Unit
t	Statistic Value from Regression Analysis, No Unit

CHAPTER 1
INTRODUCTION

1.1 Research Background

The term "safety culture" originated from the analysis report of the Chernobyl nuclear power-plant accident in 1986 (IAEA, 1986). This report introduced a new approach to investigate more deeply the root causes of incidents that extended beyond immediate engineering and technical failures. Safety was subsequently managed in a more advanced and systemic manner, becoming understood and accepted as the organisation's highest priority, referred to as safety culture (Antonsen, 2018). Other investigations of major industrial disasters such as Bhopal (1984), Piper Alpha (1998), Texas City (2007), and Deepwater Horizon (2010) concluded that despite complex engineering and technical safeguards, the systems failed catastrophically, resulting in severe injuries, fatalities, economic loss, and environmental impact. These disasters were not primarily caused by engineering breakdowns but by the combined effects of human actions and inactions within the operational system. Uttal (1983) defined safety culture as the "shared values and beliefs that interact with an organisation's structure and control systems to produce behavioural norms," while the Advisory Committee on the Safety of Nuclear Installation (ASNI) emphasized values, behaviours, competencies, and attitudes as core to safety culture (ASNI, 1993).

Insights into the factors contributing to incidents, accidents, and safety performance provided an understanding of how organisational safety culture was shaped. Values and beliefs influenced individual attitudes, which in turn shaped behaviour. These behaviours affected safety actions and inactions, influencing health and safety performance at all organisational levels. This indicated that a multilevel, dynamic, and interactive relationship existed between people and their work environment. Consequently, strategies could be developed to assess and identify safety gaps within organisations and to implement improvement plans. At the organisational level, safety culture comprises visible artefacts such as the vision, mission, and objectives, while the safety management system includes policies and processes. Employees' perceptions represented the invisible dimension of safety culture, which could be assessed through surveys, whereas behaviour and practices could be observed or monitored. A positive safety culture implied that the whole was greater than the sum of its parts and that different aspects interacted to produce collective commitment; conversely, a negative safety culture reflected partial or inconsistent commitment among individuals.

In the modern era of information and communication technology, people had become accustomed to computers and digital applications, while mobile applications emerged as a relatively new and rapidly growing medium. The safety and health sector experienced significant growth in using mobile apps to deliver behaviour-change interventions aimed at promoting safety and preventing accidents. Behaviour-change interventions were defined as “coordinated sets of activities designed to change specific behaviour patterns” (Miche et al., 2015). Traditionally, such interventions were resource-intensive and difficult to scale (Miche et al., 2011). The interest in mobile applications stemmed from their broad reach and ability to perform multiple functions, including features that enhanced person-centred engagement and safety awareness (Ricciardi et al., 2013). Although research on mobile applications for behaviour change was still developing, their use continued to grow (McKay et al., 2019). Most applications contained only a limited number of features capable of influencing behaviour (Morrissey et al., 2016). Examples included reminders (e.g., prompting employees to declare health status before work), activity tracking (e.g., encouraging safety reporting), goal-setting, and tailored information (e.g., communicating consequences of unsafe behaviour) (Haase et al., 2017). Despite the field’s early stage and the absence of consensus regarding efficacy, mobile application use in health and safety contexts became increasingly common (Oikonomidi et al., 2019).

1.2 Problem Statement

Safety culture is widely recognised as a critical mechanism for improving safety performance and preventing occupational incidents, particularly in high-risk industries such as oil and gas. Integrating safety culture into organisational operations is essential for ensuring a safe and sustainable work environment; however, its implementation remains challenging due to the need for a holistic and systemic approach that encompasses organisational structures, human behaviour, and technological enablers. Despite extensive scholarly attention, no clear consensus exists regarding the specific content, measurement, and operationalisation of safety culture, resulting in fragmented and inconsistent safety culture interventions across organisations. Extensive occupational safety research within the oil and gas sector has focused on accident causation, contributing factors, and compliance-based preventive strategies. Nevertheless, serious incidents continue to occur, leading to substantial loss of life, environmental damage, and economic consequences (Chen et al., 2021; Hassan et al., 2020). In Malaysia, official statistics reported by the Social Security Organisation (SOCSO) indicate that occupational accident cases in the oil and gas sector have consistently exceeded 400 cases annually since 2014, with 441 cases recorded in 2021 alone (Figure 1.1). The persistence of these accident trends suggests that conventional safety management systems, when applied in isolation, are insufficient to address the underlying behavioural and cultural determinants of occupational incidents.

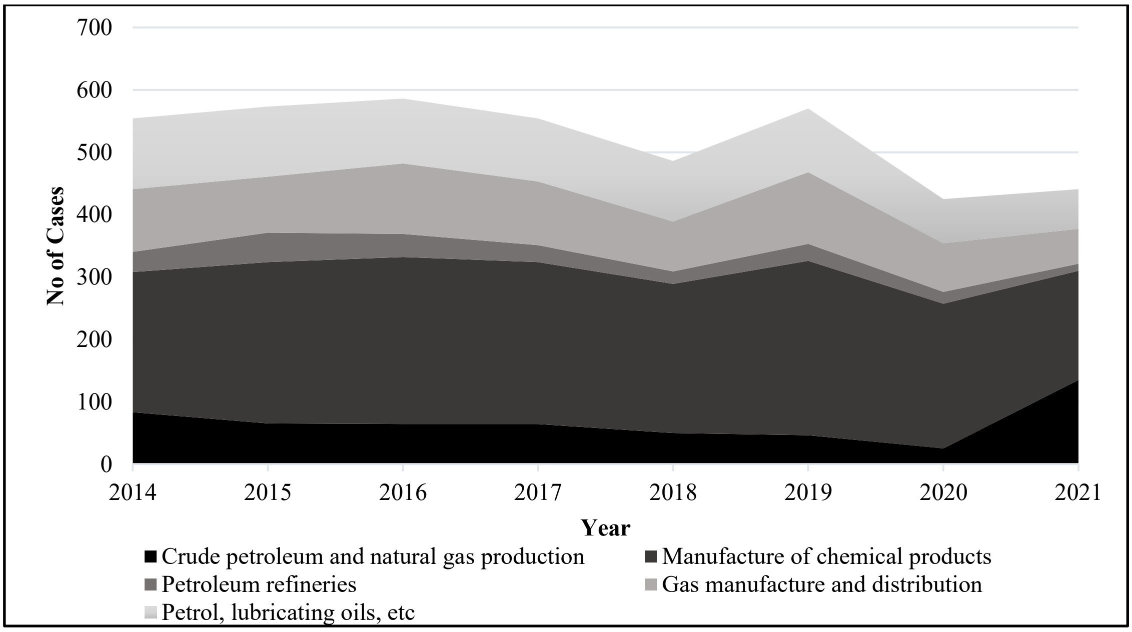

Figure 1.1 Number of Accidents Reported per Year for Different Sectors of the Oil and Gas Industry (SOCSO, 2021)

Recent empirical evidence from a safety culture maturity assessment conducted within the Malaysian oil and gas industry further substantiates this concern. The study revealed that, although organisations generally demonstrated proactive to generative levels of safety culture maturity overall, this maturity was not uniform across all safety culture dimensions. As shown in Table 1.1, several behavioural dimensions including incident perception, training and competency, and leadership engagement exhibited comparatively lower mean scores than other dimensions, despite the presence of formal safety management systems and ISO 45001 certification. These findings indicate that while structural and procedural elements of safety culture are relatively well established, critical behavioural components remain insufficiently embedded.

Table 1.1
Maturity of Safety Culture Scores based on Safety Culture Dimensions in the Malaysian Oil and Gas Sector[1].

Dimension	**Pathological (%)**	**Reactive (%)**	**Calculative (%)**	**Proactive (%)**	**Generative (%)**	**Mean ($\overline{X}$)**
Q1: Communication	1.00	2.00	12.00	32.92	52.00	4.33
Q2: Commitment and leadership	1.55	4.35	9.32	41.61	43.17	4.20
Q3: Rewards and recognition	1.24	2.48	20.81	43.79	31.68	4.02
Q4: Incident perception	2.80	0.00	15.22	39.44	42.55	4.19
Q5: HSE & profitability	1.00	4.00	14.00	39.00	42.00	4.19
Q6: Contractor management	1.00	3.42	20.19	25.78	49.69	4.20
Q7: Training and competency	1.86	2.17	18.63	38.51	38.82	4.10
Q8: HSE department	1.00	2.00	18.32	32.00	47.00	4.25
Q9: Intervention	0.62	1.86	10.56	47.20	39.75	4.24
Q10: Consequence management	1.00	1.24	18.94	42.86	36.00	4.14
Q11: Process safety	1.00	2.00	14.00	49.00	33.00	4.15
Q12: Procedures	1.00	1.00	10.00	14.00	74.00	4.63
Q13: Incident investigation	0.93	2.48	13.04	30.99	42.55	4.22
Q14: Hazard reporting	0.93	3.11	12.73	45.96	37.27	4.16
Q15: HSE lesson learnt	0.93	0.31	11.80	26.71	60.25	4.45
Q16: Safety meeting	0.62	2.48	16.46	34.16	46.27	4.23
Q17: Audit	0.31	1.24	14.29	38.82	45.34	4.28
Q18: HSE benchmarking	1.00	2.00	19.00	39.00	39.00	4.15

Note: Safety culture maturity levels were assessed using mean scores, with ranges of 1.00 - 1.99, 2.00 - 2.99, 3.00 - 3.99, 4.00 - 4.49, and 4.50 - 5.00 corresponding to pathological, reactive, calculative, proactive, and generative levels, respectively.

The uneven distribution of safety culture maturity is further illustrated in Figure 1.2, which shows that most safety culture dimensions cluster within the proactive range rather than the generative level. This trend suggests that organisations are capable of

[1] Rahim, H., Dom, N. C., & Dapari, R. (2025). Safety Culture Maturity Assessment: Insights and Improvement Opportunities for the Oil and Gas Sector. *Malaysian Journal of Medicine & Health Sciences*, *21*(5).

anticipating safety risks and implementing preventive measures, yet struggle to consistently internalise safety as a shared value that drives everyday behaviour across all organisational levels. Moreover, Figure 1.3, which depicts the overall organisational safety culture maturity level, highlights the coexistence of relatively high overall maturity with persistent gaps in specific behavioural domains. This mismatch underscores a key limitation of existing safety culture initiatives: high aggregate maturity scores do not necessarily translate into consistent behavioural safety practices on the ground.

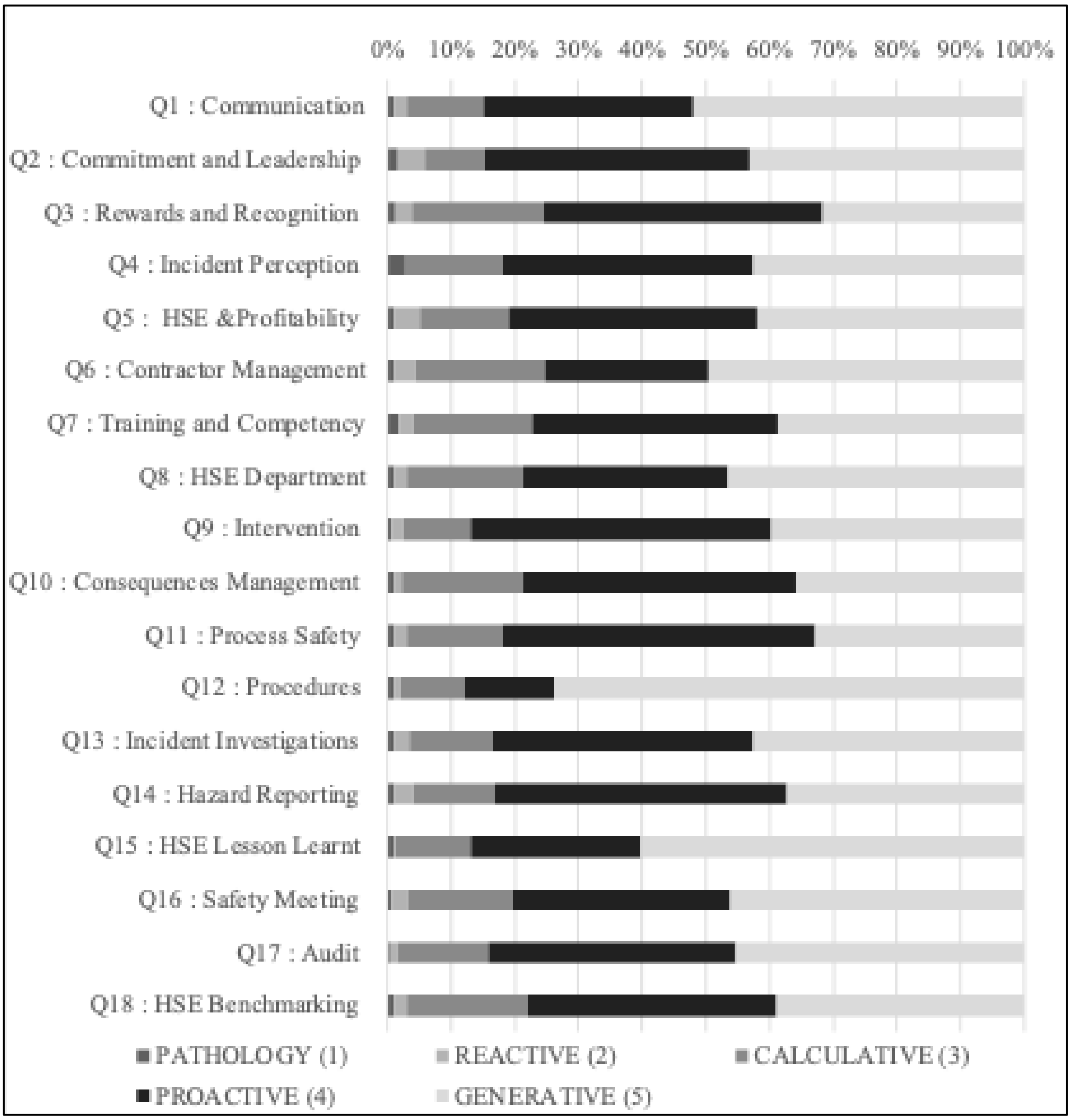

Figure 1.2 Trend Distribution of Safety Culture Maturity Level (Rahim et al., 2025)

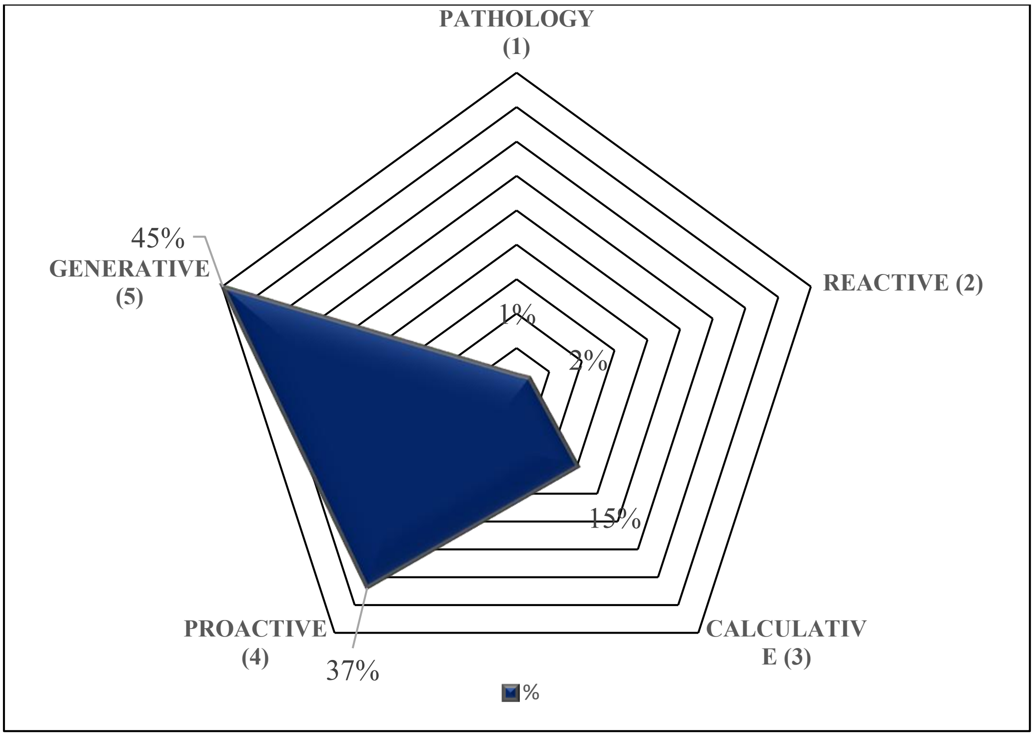

Figure 1.3 Organisation Safety Culture Maturity Level

These findings align with previous research identifying human error and unsafe behaviour as the most immediate precursors to workplace accidents (Fu et al., 2020). Central to this challenge is the difficulty of identifying and influencing personal attitudes, perceptions, beliefs, and values, which form the foundation of safety culture and directly shape individual behaviour (Cooper, 2000). The safety culture maturity assessment demonstrates that these behavioural attributes, particularly incident perception and leadership engagement, remain weak even in organisations that perform well in other safety culture dimensions. This indicates a critical translation gap between organisational safety intentions and frontline safety behaviour. Importantly, the empirical findings also suggest that current safety culture initiatives tend to emphasise assessment and compliance rather than continuous behavioural reinforcement. While maturity assessments are effective in identifying gaps, they offer limited practical guidance on how to operationalise behavioural change in real time. This limitation is particularly evident in dimensions related to learning continuity, leadership visibility, and individual risk perception, which were consistently identified as areas requiring improvement.

In parallel, there has been growing interest in mobile and digital applications as behavioural interventions to promote occupational health and safety. However, most existing safety applications function primarily as reporting or monitoring tools and are rarely grounded in safety culture theory, behavioural change principles, or systems thinking. Consequently, empirical evidence demonstrating their effectiveness in addressing specific safety culture maturity gaps remains limited. Taken together, these findings highlight a critical and unresolved problem: although safety culture maturity assessments can identify behavioural weaknesses, organisations lack theory-driven, systems-oriented, and operational tools to translate these findings into sustained behavioural change. This gap is particularly evident in the Malaysian oil and gas industry, where accident trends remain persistently high despite generally positive safety culture maturity scores.

Accordingly, this research addresses an important gap by focusing on the development of a behavioural safety culture mobile application framework tailored to the Malaysian oil and gas industry. Building directly on empirical evidence from safety culture maturity assessments, the proposed framework seeks to operationalise key behavioural dimensions, namely incident perception, training and competency, leadership engagement, and communication. By embedding behavioural safety principles within a digital platform aligned with organisational systems, this study aims to strengthen the translation of safety culture maturity into consistent safety behaviour and improved occupational safety performance.

Although mobile applications have increasingly been adopted within occupational safety and health management, most existing applications are designed primarily for incident reporting, inspection, compliance monitoring, or training administration. Limited attention has been given to developing a theory-driven digital intervention that systematically integrates psychological, behavioural, and situational dimensions of safety culture into a unified framework. Furthermore, existing studies rarely prioritise safety culture elements based on stakeholder preferences or validate their relative influence on safety outcomes using empirical modelling techniques. Therefore, the novelty of this study lies in the development of a Behavioural Occupational Safety Culture Application (BOSCA) derived from a systematic review, prioritised through the Analytic Hierarchy Process (AHP), validated using Structural Equation Modelling (SEM), and operationalised through a Progressive Web Application (PWA). Unlike conventional safety applications, BOSCA focuses on strengthening proactive safety culture through behavioural reinforcement mechanisms, safety communication, safety ownership, hazard reporting, and safety learning. The behavioural dimension was selected as the primary focus because it was identified as the most preferred safety culture dimension by stakeholders and demonstrated the strongest contribution to safety culture performance. This evidence-based integration of safety culture theory, stakeholder prioritisation, and digital intervention represents a significant contribution to both safety culture research and practical safety management within the Malaysian oil and gas industry.

1.3 Research Gaps

Although the oil and gas industry is governed by stringent safety standards, procedures, and practices, accident rates in Malaysia have not shown significant improvement. Several regulatory frameworks, such as the Occupational Safety and Health (Amendment) Act 2022, the Petroleum (Safety Measures) Act 1984, and the Petroleum Regulation 1974, have provided comprehensive guidance to ensure compliance with safety requirements. Nevertheless, the persistence of workplace accidents and fatalities suggests that regulatory compliance alone has not been sufficient to achieve the long-standing industry goal of "zero accidents." This situation raises the critical question of which factors remain unaddressed within existing safety management systems.

One of the key elements that appears to have been overlooked is safety culture. Previous studies demonstrated that unsafe acts and unsafe behaviours were among the primary contributors to workplace accidents (Dodoo & Al-Summarraie, 2019; Alkhaldi et al., 2017). For instance, Ebrahimi et al. (2016) found that safety culture significantly predicted unsafe behaviour in the Iranian oil and gas industry, where weaker safety cultures were associated with higher incidences of unsafe acts. Similarly, Tong et al. (2020) revealed that personality traits such as impulsivity and sensation-seeking were positively correlated with unsafe behaviour among oil and gas workers in China. These findings underscored the need for continued research to better understand how safety culture influences unsafe acts and to design effective, context-specific strategies for strengthening organisational safety culture.

However, limited attention has been given to systematically identifying, prioritising, and validating safety culture dimensions before translating them into a digital intervention. Although psychological, behavioural, and situational dimensions collectively influence safety culture, existing digital safety applications rarely employ an evidence-based approach to determine which dimensions should be prioritised for implementation. Furthermore, most existing applications focus on compliance, reporting, inspection, and monitoring functions rather than strengthening proactive safety culture through behavioural reinforcement mechanisms. The majority of prior studies focused on traditional interventions such as training, audits, and communication programs, with limited emphasis on how technology could be leveraged to sustain proactive safety culture practices. This gap highlighted the need for a digital solution capable of engaging employees in real time, promoting behavioural safety and strengthening organisational safety performance.

To address these gaps, this research identified the key elements of safety culture and translated them into the design and development of a mobile application framework tailored to the oil and gas industry. The study developed an evidence-based, organisation-suited digital tool that facilitated employee participation, enhanced proactive safety behaviour, and enabled real-time safety engagement between workers and management. The resulting framework contributed both theoretically and practically to advancing the understanding and operationalisation of proactive safety culture through digital technology.

The novelty of this study lies in the integration of systematic review, Analytic Hierarchy Process (AHP), Structural Equation Modelling (SEM), and digital intervention development to identify, prioritise, validate, and operationalise safety culture dimensions. The behavioural dimension was subsequently selected for application development because it demonstrated the highest stakeholder preference and strongest contribution to safety culture outcomes. This evidence-based prioritisation differentiates BOSCA from conventional safety applications and existing safety culture studies.

1.4 Significances of Study

1.4.1 Theoretical Significance

This study contributed to advancing the understanding of the factors that influence safety culture within the oil and gas industry. Drawing upon an extensive literature review and empirical evidence, the research refined the conceptualisation of safety culture by categorising its determinants into three fundamental dimensions:

psychological, behavioural, and situational. These dimensions provided a comprehensive framework for interpreting how individual and organisational attributes collectively shape safety outcomes. Furthermore, the study integrated safety culture theory with mobile technology design principles to establish a culturally adapted framework for developing a safety-related mobile application. The framework bridged theoretical constructs with practical digital tools aimed at enhancing proactive safety engagement. The evaluation of the mobile application employed an instructional design approach (Alessi & Trollip, 2001), which provided a systematic method for assessing its pedagogical logic, user experience, and behavioural impact. Collectively, these theoretical contributions enriched the body of knowledge on how digital interventions can operationalise and strengthen safety culture in high-risk industries.

1.4.2 Practical Significance

This research also delivered important practical contributions. It produced a reliable, culture-based, and self-directed mobile application that promoted and reinforced safety culture within organisations. The application was designed to be accessible to all employees with mobile devices and internet connectivity, enabling widespread participation in safety and health initiatives. The engagement of workers in safety and health activities benefited both employees and management. Employees were able to identify site-specific hazards that might otherwise be overlooked and to provide insights that enhanced the organisation's risk-control strategies. Such participatory practices aligned with international occupational safety standards, including ANSI/ASSP Z10, OHSAS 18001 and ISO 45001 (ISO, 2018), all of which emphasize worker involvement as a central element of safety management systems. In addition, the framework established through this study offered guidance for developing and optimizing future safety-related mobile applications suited to specific industrial contexts. The model served as a key contributor to the digitalization of safety management systems, improving the effectiveness, efficiency, and inclusiveness of occupational safety and health practices. Ultimately, the research supported the broader goal of fostering a sustainable, technology-enabled safety culture in the oil and gas industry.

1.5 Research Question

The research addressed the following research questions, which corresponded to its sequential phases of element identification, design and development, and implementation and evaluation:

i. What are the elements and dimensions of safety culture comprising situational, behavioural, and psychological components?
ii. What preferred elements, framework components, and functional features should be incorporated into the mobile application based on insights from the literature and stakeholder needs analysis?
iii. What is the level of user acceptance, perceived usefulness, and intention to use the developed mobile application among oil and gas industry employees following its implementation?

1.6 Objectives

The general objective of this study was to design, develop, and evaluate a mobile application based on a safety culture framework for the oil and gas industry in Malaysia. The specific objectives were as follows:

i. To identify, prioritise, and validate the psychological, behavioural, and situational dimensions of safety culture in the Malaysian oil and gas industry
ii. To design and develop the Behavioural Occupational Safety Culture Application (BOSCA) based on the prioritised safety culture dimensions
iii. To evaluate the validity, acceptance, and suitability of the developed BOSCA application among industry practitioners.

1.7 Limitation of Studies

Developing and implementing a mobile application across the entire oil and gas industry was a time-consuming and resource-intensive process. Therefore, this study focused on analysing factors influencing safety culture as identified in the literature and aligning them with the organisational safety objectives relevant to managing safety within the Malaysian oil and gas sector. The scope was confined to the development and evaluation of the mobile application framework rather than large-scale deployment across all industry segments.

1.8 Theoretical Framework

The theoretical framework was developed by integrating two established safety models to address key issues and adopt evidence-based strategies for improving organisational safety culture. Evidence from prior studies revealed that companies should focus approximately 80% of their culture-change efforts on behavioural and situational factors to prevent accidents and fatalities (Cooper, 2018). Meanwhile, Hudson's Safety Culture Maturity Model (Hudson, 2001) provided a structure for identifying organisational safety stages and benchmarking progress. Therefore, this framework was constructed by integrating the theoretical elements of both Cooper's Reciprocal Safety Culture Model and Hudson's Safety Culture Maturity Model into the design and development of the mobile application. This integrated approach allowed the framework to capture both behavioural dynamics and organisational maturity aspects, ensuring a comprehensive basis for promoting proactive safety culture.

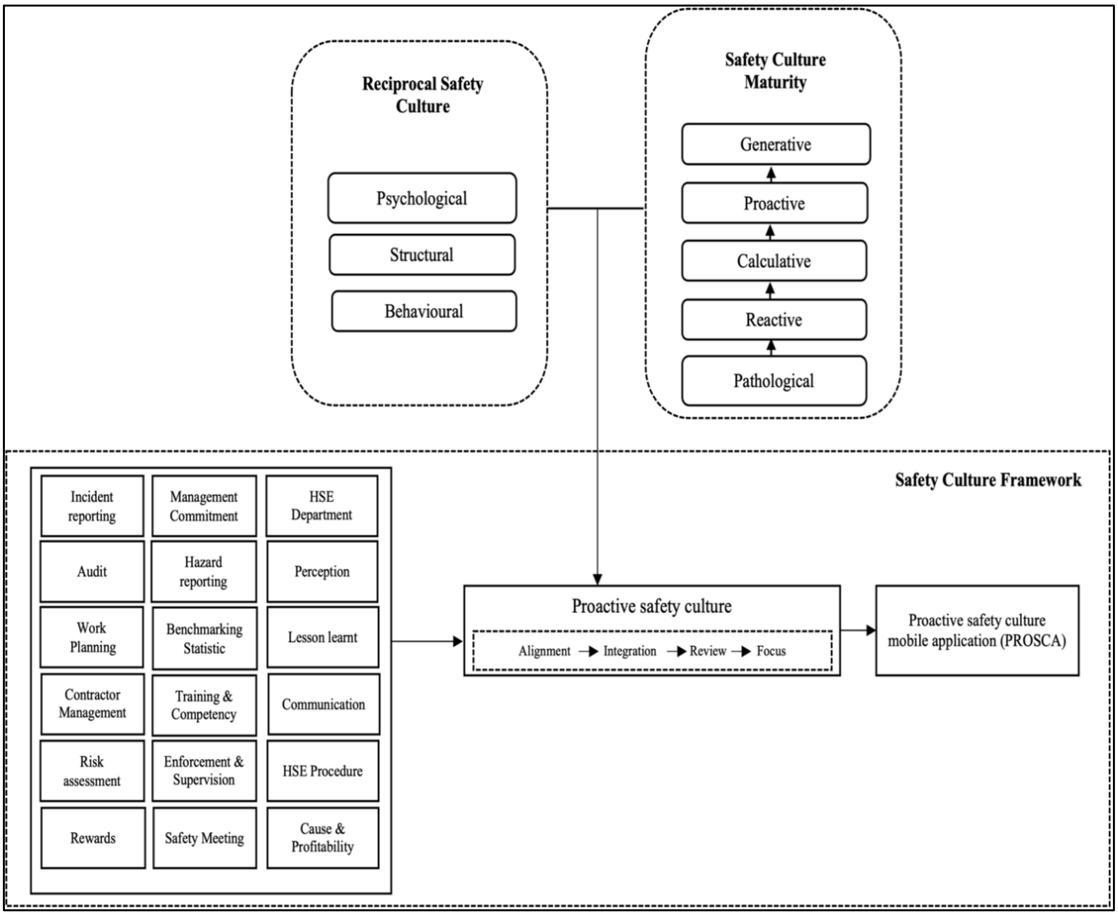

Figure 1.4 Theoretical Framework of Mobile Application (Modification from Cooper's Reciprocal Safety Culture Model (Cooper, 2016), Hudson Safety Culture Model (Hudson, 2001) and safety culture framework (Parker et al., 2006)

1.9 Conceptual Framework

The conceptual framework of this study illustrated the interrelationships among the key variables that underpinned the design and development of a proactive safety culture mobile application for the oil and gas industry. It was grounded on the assumption that digital interventions could effectively foster proactive safety behaviours by integrating safety culture principles with user-centred design. The framework encompassed several interrelated components. First, the safety culture foundation drew upon established frameworks within the oil and gas industry, identifying core behavioural, psychological, and situational elements that encouraged proactive engagement in safety practices. Second, user-centred design ensured that the application aligned with user needs, preferences, and work behaviours, promoting intuitive interaction and engagement. Third, proactive features such as training modules, safety checklists, and incident reporting tools acted as behavioural reinforcements to enhance learning and preventive action. Fourth, communication and collaboration mechanisms facilitated knowledge sharing among workers, supervisors, and management, thereby strengthening organisational learning and collective responsibility. Fifth, data collection and analytics capabilities enabled continuous monitoring of safety performance, near misses, and trends to inform data-driven safety interventions. Sixth, evaluation and improvement loops supported iterative refinement of the application's functionality to sustain its effectiveness in cultivating a proactive safety culture. Finally, security and compliance considerations ensured that the application adhered to industry standards and data protection requirements. Together, these components formed a holistic digital framework linking technology adoption with behavioural transformation, positioning the mobile application as an effective tool for maintaining a proactive safety culture in the oil and gas industry.

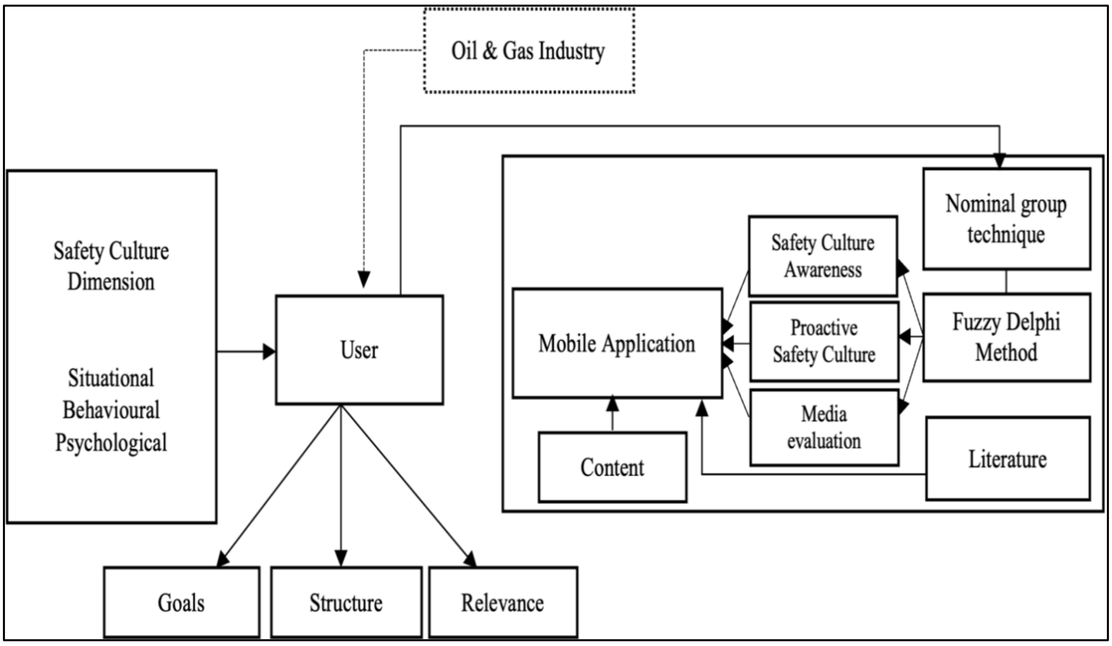

Figure 1.5 Conceptual Framework of Designing and Development of Proactive Safety Culture Mobile Application (PROSCA)

1.10 Summary

In summary, the development of this mobile application for the oil and gas industry was guided by the Reciprocal Safety Culture Model (Cooper, 2016) and the Safety Culture Maturity Model (Hudson, 2001). The application served as a portable tool to enhance the evaluation and monitoring of occupational safety and accident-prevention initiatives. Additionally, it supported management in formulating strategies to mitigate and prevent workplace incidents by emphasizing the psychological, behavioural and situational components of safety culture. The outcomes of this study demonstrated that integrating digital applications into safety management systems complemented structural and behavioural improvements within organisations, thereby advancing the establishment of an excellent and sustainable safety culture.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction on Safety Culture

The notion of “safety culture” was first mentioned in an accident report due to the 1986 catastrophe at the Chernobyl nuclear power plant. Since the release of this report, the term “safety culture” has undergone extensive examination in different fields of study to comprehend better its guiding principles (Choudhry et al., 2007). As a result, there are increasingly more publications on safety culture, making it challenging to grasp the subject comprehensively. Safety culture is considered a complex topic based on the contextual perspective of the organisation. As mentioned earlier, the concept originated in the nuclear organisation field. The safety culture notion is, nevertheless, expanded to a wider variety of other safety topics and is not just addressed in the organisational safety context. This includes quality of care, patient safety, and patient experience in hospitals attributed to safety culture within the healthcare sector (Sammer et al., 2020). Apart from that, the safety culture’s concept is also implemented in other sectors, such as manufacturing, construction, finance, transportation, aviation, education, and many others (Van Nunen et al., 2018). This multidisciplinary field of research has given rise to various methods for studying and evaluating organisational safety culture, including quantitative methods (Warszawska et al., 2016).

The intricacy of the safety culture’s topic and the fact that it is being published with increasing frequency make it an important study for bibliometric analysis. The bibliometric methodology is applied to assess and characterise the study patterns and performance with respect to journals, authors, institutions, and countries, as well as to capture and represent the patterns of collaboration among them (Li & Zhao, 2015). Furthermore, this method helps to identify research gaps in a particular subject area (Gall et al., 2015). Bibliometrics can also be used as a scientific method in decision-making. It has been widely employed to compare and evaluate the accomplishments of authors, journals, regions, as well as institutions. In addition, bibliometric data can assist research institutions and policymakers in allocating research funds (Ugolini et al., 2015).

This review's purpose is to present a general summary with respect to the safety culture publications' salient characteristics over the previous ten years using bibliometric analysis. The data in this study provide a snapshot of the research field in safety culture and can help practitioners from different sectors by understanding the key implications of research topics, journals, method analysis, geographic regions, authors, industry, and institutions.

2.2 Publication Performance and Growing Trend in Safety Culture Research

Data from articles published in the study years from 2011 to 2021 were analysed, and Figure 2.1 illustrates the number of citations and articles per publication by region. There were only 511 publications relating to safety culture in 2011; however, since 2012, there has been a dramatic rise in the number of publications. As indicated, the number of publications on the safety culture topic had increased, with the exception of 2014 (n = 832) and 2016 (n = 990), when there was a significant decrease. The burning question is whether the demand for safety culture publications will continue to rise in the upcoming decades.

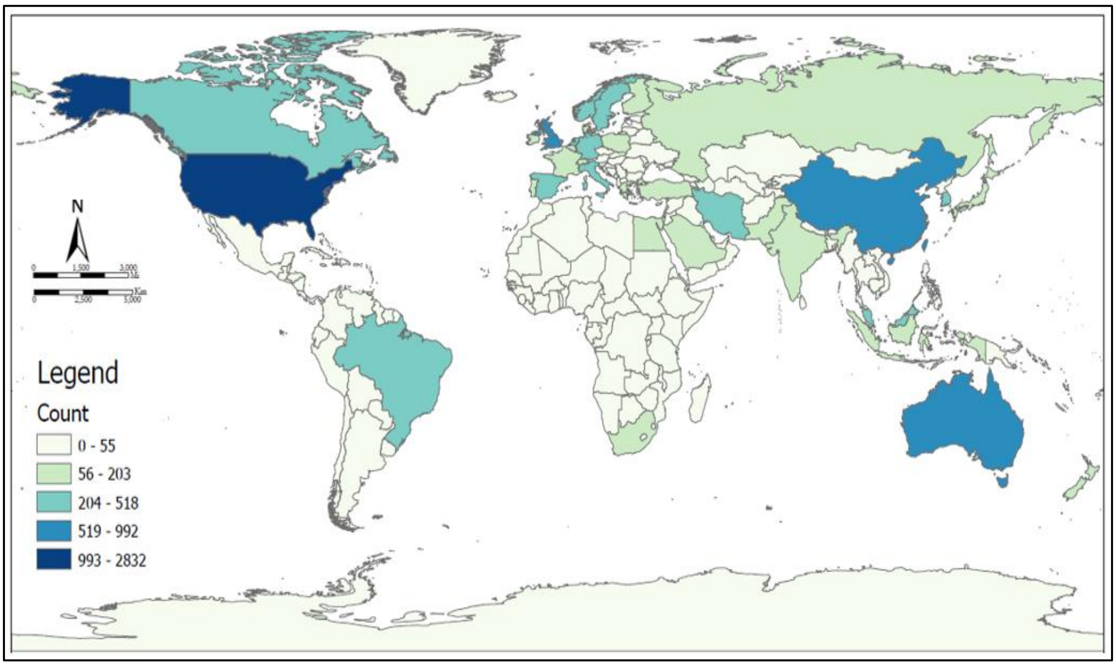

Figure 2.1 Map Illustrating the Frequency of Publications for the Most Productive and Leading Nations on Choropleth Maps Recorded for the Topic of Safety Culture

Although it is challenging to pinpoint a cause for the rise in articles published on safety culture, Price's Law has provided some insight into why there has been such a marked rise in the number of research articles published in a certain field (Price, 1963).

Price's Law explains that research goes through four phases, beginning with the precursor phase, in which a modest group of researchers begins to explore and publish a new research topic. The next stage is a true exponential development, in which a growing group of scientists becomes interested in various other parts of the research field that have not yet been discovered. The third stage of research focuses on consolidating the research field, while the last stage of the law concerns the decrease in the number of published papers.

By analysing the safety culture publications' global research trends from 2011 to 2021, this review evaluates the research subjects in those publications. Numerous studies on "safety culture" have been carried out over the past 10 years. Therefore, the volume of their publications has risen dramatically. In spite of the fact that the data collection was halted in June 2021, 2021 trends revealed a declining trend, and predicts that safety culture publication output will continue to increase over the next few years. Thus, 9788 publications on safety culture are included in the study, which spans 133 countries, 159 journals, and 160 institutions. Other than that, the study provided information regarding the foremost researchers in this field. Safety culture articles are published in several periodicals and attributed to various topic areas, reflecting the heterogeneity of safety culture research. Note that the study's limitations include a Scopus-only search. Though Scopus is one of the largest and most commonly used scientific databases, it may not contain all safety culture research publications. Hence, publications from the Web of Science (WoS) or PubMed might have been analysed. In addition, the bibliometric analysis uses keywords and quantitative methods. Therefore, some papers may have been included in the analysis despite addressing a topic other than safety culture, such as safety performance or safety climate.

Finally, the descriptive results of this bibliometric research might be utilised to paint a macrocosmic overview of the essential traits of publications on safety culture. The information presented in this study aids in providing a visual summary with respect to the advancements made in the safety culture research field. In addition, it may guide practitioners and researchers to explore and incorporate key findings from authors, journals, nations, institutions, sources, and research subjects.

2.3 Models of Accident Causation & Safety Culture

2.3.1 Models of Accident Causation

Earlier reviews of accidents were purely based on linear causation theories. Accidents were assumed to happen because of a series of circumstances or events that interact sequentially with each other linearly. The factors cause accidents to line up sequentially and cause a series of events which happen in a particular and recognisable order. Hence, by removing one of the causes in the linear sequence, accidents can be avoided. Table 2.1 illustrates the historical evolution of accident causation thinking from simple linear sequences to more complex and system-based interpretation forming an important theoretical foundation for contemporary safety and behavioural safety research.

Table 2.1
List of Accident Causation Models

Theory/Model	Factors	Model Type	Outcomes
Heinrich Domino (Heinrich et al, 1931)	Unsafe act and/or mechanical or physical hazards	First linear sequential theory of the accident causation	Interaction between behaviour and conditions.
Weaver's Domino (Weaver,1971)	Operational error, unsafe act or condition	Linear sequential theory	Interaction between management systems and accidents.
Adam's Domino (Adam, 1976)	Organisational errors, tactical errors i.e., unsafe act or condition	Multiple linear sequential Theory	Multiple interaction between organisational system, sub-system and unsafe act or condition.
Loss Causation (Bird and Germain,1985)	Managerial error, losses	Multi-linear Causation theory	Multi-linear interactions of the cause and effect sequence.
Multiple Causation (Petersen, 1996)	Many contributing factors	Multi-nonlinear Theory	Interaction in random fashion results in accident.
Reason's Swiss Cheese (Reason, 1997)	Active failures, Latent failures	Linear accident causation model	Interaction between hazards, defences and losses.

The foundation of complex linear models is the premise that accidents are the consequence of a linear combination of latent hazard conditions present in the system as well as unsafe behaviours. Causes at the sharp end are where individuals eventually engage closest to the accident, whereas factors further away from the accident are associated with organisational or environmental actions. Hence, the logical conclusion is that accidents may be avoided by concentrating on fortifying defences and barriers. The modern approach to accident modelling has evolved to acknowledge the necessity of non-linear accident models. These accidents might be considered to be the outcome of several mutually interacting factors that happen in actual settings. Therefore, accidents can be recognised and hindered only by acknowledging these multiple factors' interaction and combination.

2.3.2 Safety Culture Model

a) Guldenmund's (2000) three-layered organisational culture framework model

According to Guldenmund, the safety culture construct consists of three layers as illustrated in Figure 2.2. The core basic assumptions, postulations, or thoughts that constitute the bottom layer are unconscious and indefinite (invisible), and they include suppositions regarding safety that are not explicitly stated but are still used as the basis for action or argument. The core basic assumptions form the basis of the middle layer, which exemplifies the espoused values and beliefs that are operationalised as relatively explicit and conscious attitudes that serve as the targeted group functional groups), software (effectiveness of safety arrangements), as well as safety-related hardware (safety controls), respectively. Subsequently, Guldenmund claims that it would be challenging to understand an entity's safety from the artefacts on the top layer, which represent the preceding two layers and all those visible safety objects; for instance, safety posters, inspection reports, and personal protective equipment (Guldenmund, 2000).

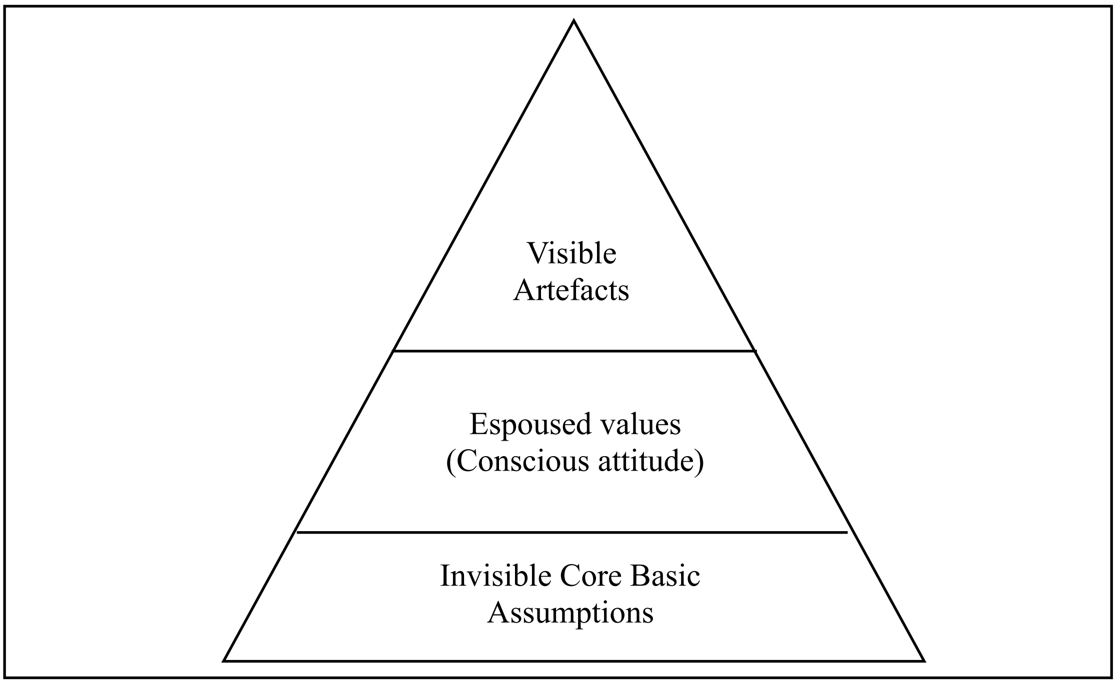

Figure 2.2 Guldenmund's Safety Culture Model (Guldenmund, 2000).

Guldenmund's model, an interpretative viewpoint, views "culture" as a pattern of basic assumptions created, found,or established by a group as it learns to deal with its issues with internal integration and external adaptation. The basic assumptions for operators, engineers, as well as executives are different. The model openly acknowledges that there will be several sub-cultures within the overall organisational safety culture. However, this model places a strong focus on comprehending an organisation's safety culture and what significance it holds for its members. The degree of agreement among the organisation's employees determines if any deduced core basic assumptions are valid. This demonstrates how challenging it is to use this framework to recognise and comprehend the safety culture construct (core basic assumptions).

b) Reciprocal Safety Culture Model

As per Bandura's model of reciprocal determinism and a comprehensive definition of safety culture by Advisory Committee for Safety in Nuclear Installations (ACSNI), Dominic Cooper developed a Reciprocal Model of safety culture (Cooper, 2000). Cooper explained the concept of safety culture as *`individual and group values and attitudes'* that refers to attitudes and perceptions of members towards safety goals; *`patterns of behaviour'* indicates members' day-to-day goal-directed safety behaviour, while the *`style and proficiency of an organisation's health and safety programmes'* indirectly indicates the quality and presence of organisational safety systems in supporting goal-directed safety behaviour. The ACSNI report acknowledges the "reciprocal" connection between these components, stating that, `... *the whole is more than the sum of the parts. The many separate practices interact to give a much larger effect'*. The reciprocal relation between an organisation's safety management system(s), the prevailing safety climate (attitudes and perceptions), as well as daily goal-directed safety behaviour, is made evident by this working definition of safety culture in Figure 2.3. Given that all of these aspects of safety culture can be explicitly measured, either individually or in combination, it is now feasible to meaningfully quantify safety culture at several distinct organisational levels, which was previously been relatively challenging. As a result, the organisational framework provides a common frame of reference for organisations when establishing benchmarking partnerships with other business units or organisations. Since individuals from various organisations will be capable of interacting in a similar language, the last aspect may be especially significant for industries that frequently utilise specialised subcontractors (for example, offshore and construction). Moreover, it offers an excellent method for comparing the prevailing safety cultures across various departments (Cooper, 2000).

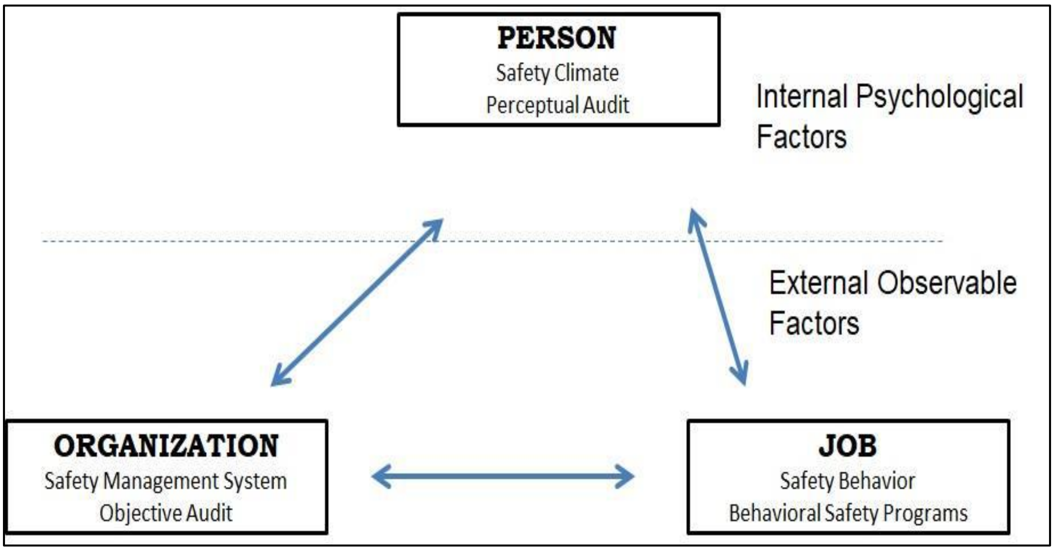

Figure 2.3. Cooper's Reciprocal Safety Culture Model (Cooper, 2000)

The Cooper's Reciprocal Model insists that the interactive framework's practical utility is deeply improved because the model may be implemented in every individual component. The author explained further that people's attitudes and perceptions regarding the prevailing safety climate could be measured through psychometric questionnaires. For example, we might uncover that a work group's views of the workplace requirements (for instance, job-related factors) and management's commitment to safety may influence their perceived levels of risk (for instance, personal factors) in the workplace (for instance, organisational factors). Similarly, we may find that commitment levels (for example, personal factors), competing goals (for example, job-related factors), as well as the quality of communication have an impact on the adoption of incentive measures to raise employees' levels of safety behaviour (for example, organisational factors). These connections hold true for safety management systems as well, in which personal factors (for example, safety training) will interact with job-related factors (for example, man-machine interfacing) as well as organisational factors (for example, resource allocation).

c) *Reason's Swiss Cheese Model*

James Reason initially created the "Swiss Cheese" accident causation model as a linear accident causation model (Figure 2.4). Because the model conceptualises accident prevention as the use of organisational defences to prevent hazards and risks from resulting in loss, it is now widely applied.

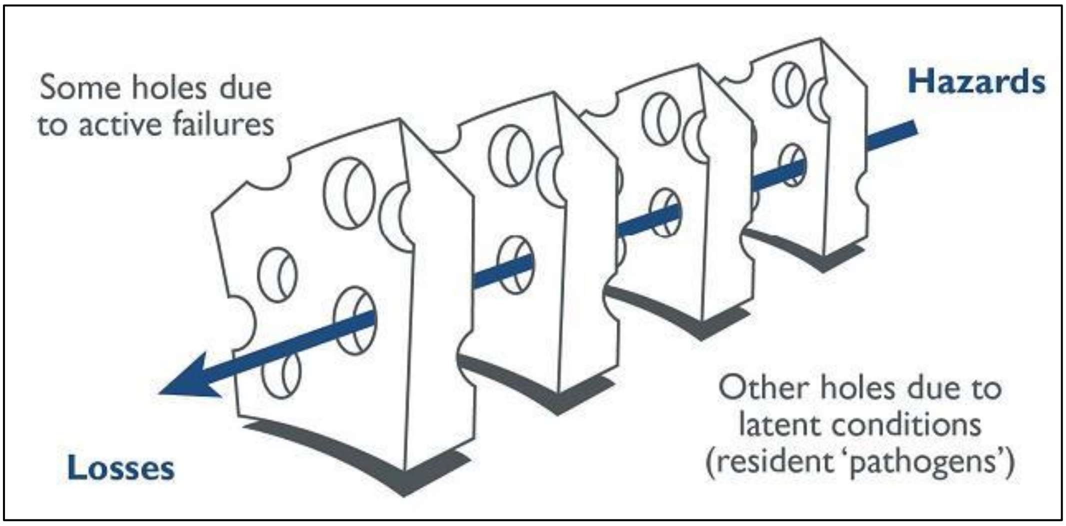

Figure 2.4 Reason's Swiss Cheese Model

Although organisational accident defences are viewed as obstacles which avert the hazards from transforming into losses, the barriers and obstacles have holes in them as slices of Swiss Cheese. Here, these shortcomings in the organisational defences are why Reason named his model Swiss Cheese (Reason, 1998). In the early to mid-1990, Reason developed a basic framework showing that defences are essentially breached by three factors: human, organisational and technical. The majority of the accidents were caused by human error rather than technological malfunction. A closer look reveals the necessity to separate the following two ways that people contribute to the failure of complex systems (Reason, 1997):

i. Active failure: those violations and errors that have an immediate detrimental impact; and
ii. Latent failures: these are actions or decisions that may have negative effects for a while before getting apparent when combined with local triggering factors to breach the system's defences, such as active failures, technical failures, and so on.

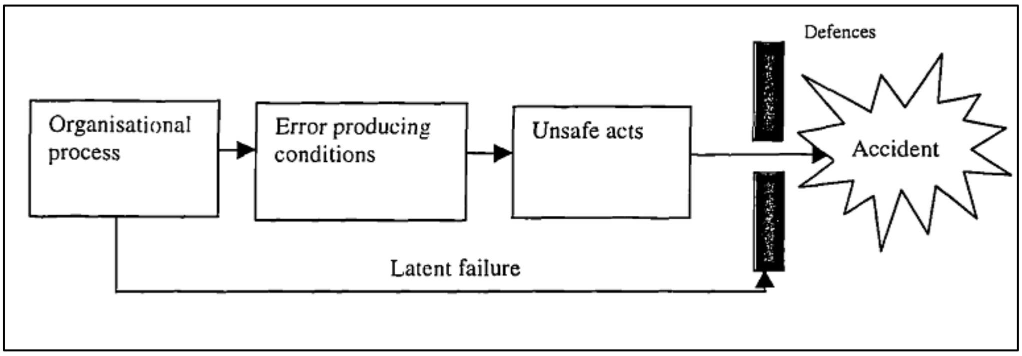

Figure 2.5 Reason's Framework of Accident Causation

In Reason's framework of accident causation (Figure 2.5), accidents are no longer attributed solely to unsafe acts at the operational level but are understood as the outcome of complex interactions between organisational processes, error-producing condition, and human actions. As illustrated in Figure 2.5, the organisational process component encompasses management decisions, organisational structures, operational procedures, and corporate culture, which collectively shape the conditions under which work is performed. These upstream decisions give rise to latent failures, which may remain dormant within the system until they interact with local workplace conditions and unsafe acts, thereby breaching existing defences and resulting in an accident. In conclusion, this model highlights a critical shift in accident causation thinking, from blaming individual failures to recognising how organisational and managerial weaknesses propagate through the system, ultimately influencing frontline behaviour and accident outcomes.

d) Reason's Swiss Cheese Model

Reason further developed an updated version of the Swiss Cheese Model (SCM), introducing significant conceptual refinements to accident causation theory. As illustrated in Figure 2.6 (Reason's Model), the author argues that any model of accident causation must incorporate three fundamental elements: hazards, defences, and losses (Reason, 1997). In this framework, safety barriers are conceptualised as successive layers of protection, positioned one behind another, each intended to prevent hazards from progressing into losses. Figure 2.6 demonstrates how hazards are managed through multiple defensive layers, including warnings, alarms, engineered safety features, and physical barriers, which operate to either control, eliminate, or separate individuals from hazards. Where cognitive understanding, awareness, and procedural guidance are insufficient, engineered systems are designed to return operations to a safe state. If these defences are breached, latent organisational conditions, local workplace factors, and unsafe acts interact along latent condition pathways, allowing hazards to penetrate remaining barriers and result in losses. Overall, this model reinforces a systems-based perspective of accident causation, highlighting how organisational and workplace-level weaknesses shape frontline behaviour and determine the effectiveness of safety barriers in preventing adverse outcomes.

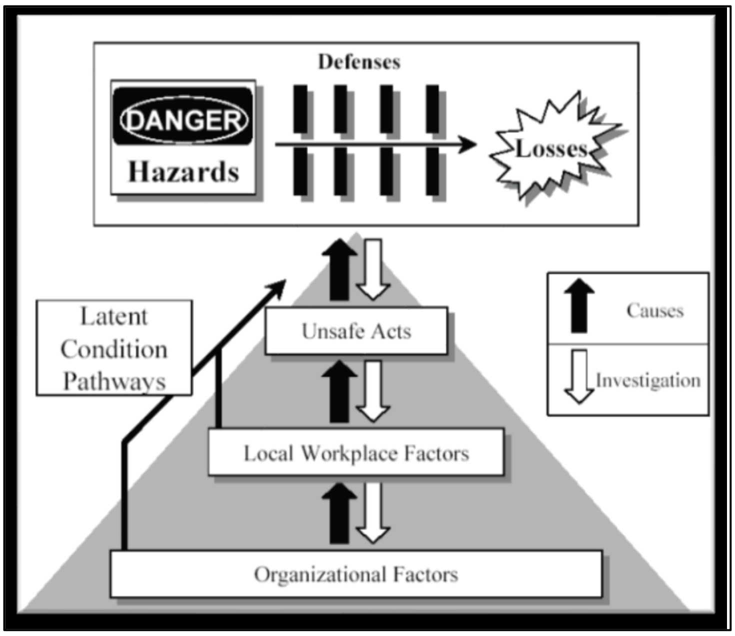

Figure 2.6 Reason's Model Published in 1997

The SCM model is a highly generic tool. However, it has been widely adopted as the conceptual basis for a range of accident analysis and safety management frameworks. These include communication and analysis systems such as the Human Factors Analysis and Classification System (HFACS), BHP's Incident Analysis Cause Method (ICAM), and Tripod Beta. The SCM has also been used as a foundation for proactive process measurement approaches, including Managing Engineering Safety Health (MESH), tailored for British Airways Engineering and Singapore Airlines Engineering Company, as well as the Proactive Assessment of Organisational and Workplace Factors (PAOWF), a technique used to measure 'leading indicators' in the United States nuclear power industry.

2.4 Proactive Safety Culture

Proactive safety culture refers to a workplace environment in which employees and management are committed to preventing accidents, injuries, and other safety incidents before they occur (ILO, 2006). This approach to workplace safety involves identifying potential hazards and taking proactive measures to mitigate or eliminate them, rather than simply reacting to accidents after they happen. Having a proactive safety culture is important for several reasons. Firstly, it helps to reduce the risk of accidents and injuries, which can have significant financial and human costs for both employees and the organisation (Rahmandoust et al., 2019, Haslam et al., 2016). Secondly, it can improve employee morale and productivity by creating a safer and more supportive work environment. Finally, it can help to establish the organisation's reputation as a responsible and reliable employer, which can be important for attracting and retaining talent.

The purpose of this review is to provide a comprehensive analysis of proactive safety culture and its importance in ensuring workplace safety. The discussion will focus on defining proactive safety culture, highlighting its key concepts and components, and exploring the benefits of implementing a proactive safety culture in the workplace. The review will also discuss the challenges and barriers that organisations may face when trying to implement a proactive safety culture, and provide suggestions for overcoming these challenges. Finally, the review will outline the best practices for implementing a proactive safety culture in the workplace and provide examples of organisations that have successfully implemented these practices. The scope of the discussion will be limited to the concept of proactive safety culture and its relevance to workplace safety. The review will not cover other aspects of workplace safety, such as compliance with regulatory requirements or specific safety protocols for particular industries.

2.4.1 Definition and Key Concepts

Proactive safety culture refers to a workplace environment in which employees and management are committed to preventing accidents, injuries, and other safety incidents before they occur (McKinnon 2013). It involves a proactive approach to identifying and mitigating potential hazards in the workplace, rather than simply reacting to accidents after they happen. The main components of a proactive safety culture include:

Hazard identification: Hazard identification involves identifying potential hazards in the workplace, such as unsafe work practices, equipment, or environments. This can be achieved through various methods, including workplace inspections, safety audits, and employee feedback. By identifying potential hazards, organisations can take proactive measures to mitigate or eliminate them, thereby reducing the risk of accidents and injuries.

Risk assessment: Once hazards have been identified, a risk assessment should be conducted to determine the likelihood and potential consequences of an incident occurring. This involves evaluating the severity of the hazard and the likelihood of it occurring, and then determining the level of risk associated with it. By conducting risk assessments, organisations can prioritise their safety efforts and allocate resources to address the most significant risks

Safety leadership: Safety leadership involves management taking an active role in promoting a culture of safety in the workplace. This includes setting clear safety goals and expectations, providing resources and training to employees, and leading by example. By demonstrating a commitment to safety, management can create a supportive work environment in which employees feel empowered to take an active role in identifying and mitigating potential hazards

Employee involvement: Employee engagement involves actively involving employees in identifying and mitigating potential hazards in the workplace. This can be achieved through regular safety training, feedback mechanisms, and incentives for safe behaviour. By involving employees in safety efforts, organisations can tap into the knowledge and expertise of their workforce, and create a culture of shared responsibility for workplace safety

Continuous improvement: A proactive safety culture involves a commitment to continuously improving workplace safety. This can be achieved through regular review and evaluation of safety policies and procedures, and implementing changes as necessary to ensure ongoing effectiveness.

A proactive safety culture involves a comprehensive approach to workplace safety that emphasizes prevention and continuous improvement. By implementing the above components, organisations can create a safer and more supportive work environment for their employees.

2.4.2 Benefits of Proactive Safety Culture

Implementing a proactive safety culture in the workplace can provide numerous benefits to both employees and the organisation. Some of the key benefits of proactive safety culture include (Kalteh et al., 2021, Cesarini et al., 2013, Haslam et al., 2016, Saujani 2016):

Reduced injury rates: One of the primary benefits of proactive safety culture is a reduction in workplace injuries and accidents. By identifying and mitigating potential hazards before they occur, organisations can create a safer work environment for their employees, reducing the likelihood of workplace injuries and illnesses.

Improved productivity: Proactive safety culture can also lead to improved productivity in the workplace. When employees feel safe and supported, they are more likely to be productive and engaged in their work. Additionally, by reducing the number of workplace injuries and accidents, organisations can avoid disruptions to workflow and reduce downtime.

(*Increased employee morale*: A proactive safety culture can also improve employee morale and job satisfaction. When employees feel that their organisation is committed to their safety and well-being, they are more likely to feel valued and respected. This can lead to improved job satisfaction, reduced turnover rates, and increased employee loyalty.

Cost savings: Implementing a proactive safety culture can also lead to cost savings for organisations. By reducing workplace injuries and accidents, organisations can avoid the costs associated with medical expenses, workers' compensation claims, and legal fee.

Here are some examples of companies and organisations that have successfully implemented a proactive safety culture and achieved positive results: Alcoa is an aluminium manufacturing company that transformed its safety culture by implementing a system called EHSMS (Environment, Health, Safety, and Sustainability Management System). The company placed a high priority on safety and provided extensive training to employees. As a result, the company reduced its injury rate by 90% over 13 years, while increasing productivity and profitability. DuPont is a chemical company that has been recognised for its safety culture for many years. The company's safety program focuses on three main areas: leadership, employee engagement, and hazard recognition. As a result of its safety efforts, DuPont has reduced its injury rate by 50% since 2007. Southwest Airlines is an airline company that places a high priority on safety. The company's safety program includes extensive training for pilots, flight attendants, and ground crew, as well as regular safety audits and inspections. As a result, Southwest Airlines has a strong safety record and has never had a fatal accident in its history.

Toyota is a car manufacturing company that has implemented a safety culture called "Total Safety Management." This culture places a high priority on safety and encourages employees to speak up and report safety concerns. As a result, Toyota has reduced its injury rate by 80% since 2000. NASA is a government agency that places a high priority on safety in all its operations. The agency has a comprehensive safety program that includes training, risk assessments, and safety reviews. As a result, NASA has achieved a strong safety record in its space missions, with no fatalities since the Challenger and Columbia disasters.

2.4.3 Challenges and Barriers to Implementing Proactive Safety Culture

Implementing a proactive safety culture can be a challenging process for companies or organisations. Some of the common challenges and barriers they may face are:

Resistance to change: Implementing a proactive safety culture often requires changes to the way things are done in an organisation. Some employees may resist these changes, feeling that they are unnecessary or that they disrupt their established work routines. This resistance can lead to a lack of buy-in from employees and slow down the implementation process. *Lack of resources*: Implementing a proactive safety culture often requires additional resources such as funding, personnel, and equipment. Organisations may face difficulty in allocating these resources, especially if they are operating on tight budgets or have competing priorities. *Communication issues*: Communication is a critical aspect of implementing a proactive safety culture. It is essential that everyone in the organisation understands the importance of safety and their role in promoting it. However, poor communication can lead to misunderstandings, lack of clarity, and confusion, which can hinder the implementation process. *Inadequate training*: Providing adequate training to employees is essential for the successful implementation of a proactive safety culture. However, organisations may face challenges in providing comprehensive training to all employees, especially if they have a large workforce or if the training is complex and requires a significant investment of time and resources. *Lack of leadership support*: Leadership plays a critical role in driving the implementation of a proactive safety culture. If leadership does not prioritise safety or does not provide adequate support for the implementation process, it can be challenging to achieve buy-in from employees and ensure that safety is embedded in the organisational culture.

In summary, implementing a proactive safety culture can be challenging, and organisations must be prepared to address these challenges and barriers to ensure the success of the implementation process. This requires a commitment from the leadership, adequate resources, effective communication, and comprehensive training for employees. In order to implement a proactive safety culture, companies or organisations need to overcome challenges and barriers such as resistance to change, lack of resources, communication issues, complacency, lack of leadership commitment, and employee engagement. The suggestions to overcome these challenges and barriers involve effective communication, leadership commitment, employee involvement, and a willingness to adapt and change. Table 2.2 lists suggestions on how to overcome challenges and barriers when implementing a proactive safety culture.

Table 2.2
Challenges and Barriers of Implementing Proactive Safety Culture

Challenges and Barriers	Suggestion to Overcome
Resistance to change	Leaders must communicate the importance of safety and involve employees in the process. Demonstrate the benefits of the proactive safety culture through success stories, metrics, and data.
Lack of resources	Leaders must allocate resources and prioritise safety. Develop a budget and plan for implementation. Seek external resources such as training and consulting services.
Communication issues	Ensure clear and consistent communication about safety procedures, expectations, and goals. Use various communication channels to reach a broad audience. Hold regular meetings, training sessions, and employee feedback mechanisms.
Complacency	Remain vigilant and continually reinforce the importance of safety. Encourage employees to report any safety concerns. Hold regular safety drills and inspections. Benchmark against other companies' safety performance.
Lack of leadership commitment	Leaders must lead by example and prioritise safety. Communicate their commitment to safety and allocate resources to support the proactive safety culture. Hold themselves and their team accountable for safety performance.
Employee engagement	Involve employees in the safety culture by providing training and development opportunities. Encourage employee feedback and suggestions for improving safety. Recognise and reward employees who contribute to the safety culture's success.

The discussion reviewed proactive safety culture in the workplace, including the benefits of implementing such a culture, challenges and barriers to its implementation, and best practices for successful implementation. The benefits of a proactive safety culture include improved safety performance, increased employee engagement, and enhanced productivity. Challenges and barriers to implementing a proactive safety culture include resistance to change, lack of resources, and communication issues. Best practices for successful implementation include leadership commitment, safety planning, communication and employee involvement, continuous improvement, recognition and rewards, and evaluation and review. By following these best practices, companies can create a safer workplace, increase employee engagement and satisfaction, and improve overall productivity.

Proactive safety culture is essential in ensuring workplace safety and creating a safer work environment. It involves a comprehensive approach to safety that prioritises prevention, hazard identification, and continuous improvement. By implementing proactive safety culture, companies or organisations can benefit from improved safety performance, reduced injuries and accidents, increased employee engagement and satisfaction, and enhanced productivity. Companies that prioritise safety demonstrate their commitment to their employees' well-being and create a positive workplace culture that fosters trust and loyalty among employees. In today's business landscape, where safety regulations are increasingly stringent, and the costs of accidents and injuries can be substantial, companies that prioritise proactive safety culture will have a significant competitive advantage. Therefore, it is crucial for organisations to prioritise and invest in proactive safety culture to ensure workplace safety and create a positive workplace culture that benefits both the organisation and its employees.

2.4.4 The Difference Between Proactive Safety Culture and Reactive Safety Culture

Proactive safety culture and reactive safety culture are two different approaches to managing safety in the workplace. Both approaches have their strengths and weaknesses, and understanding the differences between them is important for effective safety management. Proactive safety culture is a preventative approach that emphasizes identifying and addressing potential hazards before they lead to accidents or incidents. This approach involves a commitment to safety from all levels of the organisation, including leadership, employees, and contractors. Proactive safety culture includes factors such as hazard identification and assessment, safety training, communication, and continuous improvement. Organisations that promote a proactive safety culture tend to have fewer accidents and incidents because they focus on preventing them before they occur. Some examples of proactive safety culture in action include pre-task planning, job hazard analysis, and regular safety audits. Reactive safety culture, on the other hand, is a responsive approach that focuses on responding to accidents or incidents after they have occurred. This approach involves investigating the causes of accidents and incidents, identifying corrective actions, and implementing changes to prevent similar incidents from happening in the future. Reactive safety culture includes factors such as incident reporting, investigation, and corrective action. While reactive safety culture is an important aspect of managing safety in the workplace, it is generally considered to be less effective than proactive safety culture, as it is often too late to prevent the accident or incident.

There were a clear differences approach between proactive and reactive safety culture elements (Table 2.3). Proactive safety culture focuses on preventing accidents and incidents from occurring by identifying potential hazards and risks and taking action to eliminate or mitigate them, while reactive safety culture focuses on responding to accidents and incidents after they occur and taking corrective action to prevent recurrence. Proactive safety culture takes a preventative approach, aiming to reduce the likelihood of accidents and incidents, while reactive safety culture takes a responsive approach, addressing incidents and accidents after they happen.

Table 2.3
Summary of the Main Differences Between Proactive and Reactive Safety Culture

Criteria	**Proactive Safety Culture**	**Reactive Safety Culture**
Focus	Preventing accident	Responding to accident after occurred
Emphasize	Hazard identification and assessment, safety training, communication and continuous improvement	Incident reporting, investigation and corrective action
Approach	Preventive	Responsive
Timeframe	Before accident occur	After accident occur
Benefits	Accident prevention	Identification of root cause and corrective action

In addition, proactive safety culture emphasizes a safety-first mindset and encourages employees to priorities safety in their work, while reactive safety culture may be more focused on meeting regulatory requirements or addressing safety issues only after they have been identified. Proactive safety culture emphasizes open communication and transparency, with employees encouraged to report potential hazards or safety concerns, while reactive safety culture may have a more closed communication approach with employees only reporting incidents or accidents when they occur. Furthermore, proactive safety culture emphasizes continuous improvement, with ongoing hazard identification and risk assessments, and a focus on developing and implementing new safety procedures and technologies to improve safety performance. Reactive safety culture, on the other hand, may have a more limited focus on continuous improvement, with corrective actions being taken to address incidents or accidents, but with less emphasis on ongoing hazard identification and risk assessments.

There have been several studies that suggest that a proactive safety culture is more effective in promoting safety than a reactive approach. A study by Guldenmund (2010) found that organizations with a proactive safety culture were more effective in preventing accidents than those with a reactive safety culture. In a study by Clarke (2003), it was found that organizations with a proactive safety culture had lower accident rates and higher employee engagement in safety than those with a reactive safety culture. Another study by Zohar and Luria (2005) found that a proactive safety culture was associated with lower accident rates and higher levels of safety compliance and safety participation among employees. Overall, these studies suggest that a proactive safety culture, which emphasizes prevention and continuous improvement, is more effective in promoting safety than a reactive approach, which focuses on responding to incidents after they occur. In conclusion, proactive safety culture is generally considered to be more effective in preventing accidents and incidents and promoting a safer work environment. It requires a long-term commitment to safety and a willingness to invest in safety measures and training. Reactive safety culture, while still important, is less effective in preventing accidents and incidents as it focuses on addressing safety issues after they occur.

This study adopts a proactive safety culture approach because the objective of BOSCA is to encourage hazard identification, safety communication, incident learning, and preventive safety actions before accidents occur. Unlike a reactive safety culture, which focuses on responding to incidents after their occurrence, a proactive safety culture emphasises anticipation, prevention, continuous improvement, and employee participation. Therefore, the design and functionality of BOSCA are aligned with the principles of proactive safety culture.

2.5 Review on Safety Culture in Malaysian Industries[2]

Safety culture is considered a key element that confirms the context for an organisation's awareness of the importance of safety (Schulman, 2020). Furthermore,

[2] Rahim. H., Dom. N. C., Dapari. R., and Precha. N. (2023). A Mapping Review on Safety Culture in Malaysian Industries: A Research Report from 2007 to 2022. *Journal of Sustainability Science and Management. 18(12), 136-150.*

safety culture reflects and constructs organisational psychological and behavioural characteristics that can influence the success or failure of occupational safety and health programmes (OHS) (Tear *et al*., 2020). With the growing awareness of safety culture as a key indicator of organisational safety outcomes, regulators in various industries have begun to emphasise safety elements in their business requirements and audits (Naevestad *et al*., 2019). With this in mind, it is not surprising that significant efforts are being made to develop an evidence-based strategy to OHS address a variety of safety issues across numerous industries (Cunningham *et al*., 2020).

The rapid economic growth of industrialisation has significantly impacted income inequality and quality of life, but it has also contributed to an increase in occupational accidents. Note that each organisation has different elements of adaptive safety culture that help to improve safety performance (Beus *et al*., 2010). Accident reports in Malaysia are compiled and managed by the Department of Occupational Safety and Health (DOSH) Malaysia, allowing for continuous assessment of safety performance in all industrial sectors. Note that the number of injury cases is increasing in all industries. Malaysia's national occupational injury statistics recorded 21,534 injury cases for all industries in 2021, with an injury rate of 1.43 per 1,000 workers (DOSM, 2022). However, the literature on safety culture rarely discusses the variables of safety culture in different industries. It is important to examine the research conducted, especially from a Malaysian perspective, as the Malaysian Occupational Safety and Health Master Plan 2021-2025 (OSHMP25) emphasises the need for a preventive culture in all industries to promote a healthy work culture that benefits employees, organisations, and the nation. Therefore, there is a need for a baseline study and discussion on how the predictive factors of safety culture research from different industries can be applied to understand safety culture and other ways to better manage safety in the workplace.

Therefore, the systematic review's objective was to explore the safety culture research conducted in Malaysia over the past decade. The findings of this study can be utilised to deepen and make the topic of safety culture practical by improving the understanding of the interactions between industries and contextual variables in a particular workplace. This systematic review provides new empirical evidence on safety culture studies across all industries in Malaysia. The authors prepared, analysed and reported the scoping review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The comprehensive reporting guide, illustrative examples and best practices for large scoping studies provided by PRISMA were ideal for this review. Nevertheless, there are other published standards for conducting systematic scoping reviews (Peter *et al*., 2015, Xiao & Watson, 2019, Prill *et al*., 2021). A total of 86 articles were found during the search. We found 66 studies after eliminating duplicates and then selected 13 studies from 25 different safety culture topics.

2.5.1 Characteristic of Study Design

Table 2.4 provides an overview of the characteristics of safety culture research. The studies examined were published between 2006 and 2021 and are organised by journal category in Scopus and WoS. Other than that, cross-sectional research appeared to be the predominant methodological design applied to all articles reviewed to determine the state of safety culture research in Malaysia. In line with the reviews, all studies employed questionnaires as a measurement tool to assess safety culture in Malaysian organisations. Previous research on safety culture in organisations has employed surveys, qualitative and anthropological techniques, accident investigations, and more (Hopkins, 2006). Various safety culture questionnaires have been used in research and organisational development up to this point (Choudhry *et al.,* 2007).

Table 2.4
Characteristic of Safety Culture Research in Malaysia from 2006 until 2022

References [ID]	Year	Industry	Participant	Instrument	Safety Culture Predictors	Safety culture aspect	Research Focus
Naji et al., [1]	2022	Petrochemical	All employees	Questionnaire	Positive relationship between safety culture and safety communication (p<0.001).	Behavioural	Relationship between safety factors and safety culture
Mohamad et al., [2]	2022	Oil and Gas	Managers & Engineers (Interview) All employees (Questionnaire)	Interview Questionnaire	Safety culture, supportive environment, social media perceived usefulness, management commitment, perceived organisational support, employee crisis perception and employee affective commitment are positively associated with communication (ICC) in oil and gas (p<0.001).	Behavioural	Factor associated with safety culture
Al-Mekhlafi et al. [3]	2021	Oil and Gas	Tanker driver	Questionnaire	Safety culture had a positive and significant impact on driving performance (p<0.000).	Situational	Prediction of safety culture model framework
Naji et al., [4]	2021	Oil and Gas	Upstream production and operational	Questionnaire	Psychosocial hazard has a significant effect on safety performance (p< 0.000).	Psychological	Relationship between safety factors and safety culture.

References [ID]	Year	Industry	Participant	Instrument	Safety Culture Predictors	Safety culture aspect	Research Focus
Nadarajan et al., [5]	2020	Healthcare	Medical student	Questionnaire	There was significant difference between among senior and gender compared to junior medical students on APRR rate ($p<0.001$).	Behavioural	Factor associated with safety culture
Musa & Isha [6]	2020	Aviation	Airport ground handler	Questionnaire	Work environment, pressure to for job completion, safety communication and reporting, employees' perception of management commitment, training and competency, and voluntary policy intervention have predictive significance toward accidents and near misses.	Situational, Psychological & Behavioural	Relationship between safety factors and safety culture
RJ et al., [7]	2019	Healthcare	Doctor Nurse Pharmacist Clinical and Non-clinical staff	Questionnaire	Not applicable	Behavioural	Factor associated with safety culture
Sivanandy et al., [8]	2016	Healthcare	Pharmacist	Questionnaire	Significant difference in patient safety attitude among seniority and gender of pharmacists ($p<0.05$).	Behavioural	Factor associated with safety culture

References [ID]	Year	Industry	Participant	Instrument	Safety Culture Predictors	Safety culture aspect	Research Focus
Samsuri *et* al., [9]	2015	Healthcare	Pharmacist	Questionnaire	Significant correlation for overall safety culture and number of medication errors reported for pharmacists working in the hospital ($p<0.05$).	Behavioural	Relationship between safety factors and safety culture
Yulia et al., [10]	2015	Manufacturing	Production line	Questionnaire	PPE and training were significant predictor for safety culture ($p< 0.05$).	Situational	Factor associated with safety culture
Ali et al., [11]	2009	Manufacturing	Food and beverage Tobacco, Electrical and Electronics, Chemical, Metal and non-metal sectors.	Questionnaire	Significant relationship between management practices and injury rates ($p<0.04$).	Behavioural	Factor associated with safety culture
Makhtar et al., [12]	2019	Education	Vocational college Instructor	Questionnaire	Significant of safety knowledge, training, safety communication, safety rules, safety training, peers, and personnel protective equipment (PPE) had a significant positive relationship with safety culture ($p < 0.01$).	Psychological, Behavioural, Situational	Relationship between safety factors and safety culture

References [ID]	Year	Industry	Participant	Instrument	Safety Culture Predictors	Safety culture aspect	Research Focus
Hassan et al., [13]	2007	Construction	Large & Small projects	Questionnaire	Not applicable	Psychological	Factor associated with safety culture

2.5.2 Major Finding Concerning Safety Culture Research

A total of seven different types of industries were found in this review, indicating that research on safety culture in Malaysia since 2007 has mainly focused on the health sector (30%), the oil and gas industry (23%), and the manufacturing sector (15%) (Table 2.5). This result is congruent with bibliometric studies on safety culture, in which the topic category "health sciences & services" is listed five times in the top ten most active journals (Van Nunen *et al*., 2018). In Malaysia, the oil and gas industry is the backbone and main growth sector of the country's economy, as well as the riskiest industry in the global economy (Foo *et al*., 2015). Therefore, the number of research on safety culture in the oil and gas industry should increase and diversify as the research findings can help reduce risk and improve the industry's safety performance. Other than that, this upward trend also applies to the manufacturing sector, which had the highest number of occupational injuries (7,994) and fatalities (65) in 2021 compared to the other nine industries (DOSM, 2022). However, as not all industries included in the first list of the Occupational Safety and Health Act (OSHA) of 1994 are considered in the study of safety culture, it is difficult to infer the level of safety culture in Malaysia. For example, industries not included in this survey include mining, agriculture and transportation.

Table 2.5
Characteristic Anlysis of Safety Culture Research in Malaysia

Characteristics	**(n)**	**(%)**
Industries		
▪ Aviation	1	8
▪ Construction	1	8
▪ Education	1	8
▪ Healthcare	4	30
▪ Manufacturing	2	15
▪ Oil & gas	3	23
▪ Petrochemical	1	8
Safety culture aspects		
▪ Situational	6	33.3
▪ Behavioural	7	38.9
▪ Psychological	5	27.8
▪ **Research objectives**		
▪ Factor associated with safety culture	7	53.8
▪ Prediction of safety culture model framework	1	7.7
▪ Relationship between safety factors and safety culture	5	38.5
Research outputs		
▪ Management commitment, management practices, organisation al support, recruitment	3	6.8
▪ Training and competency	6	13.6

Characteristics	(n)	(%)
▪ Communication	5	11.4
▪ Work performance	2	4.5
▪ Psychosocial	1	2.3
▪ Employee perception	3	6.8
▪ Policy	1	2.3
▪ Attitude and behaviour	3	6.8
▪ Influence of peer	1	2.3
▪ Safety rule, safety procedure	1	2.3
▪ Personal protective equipment (PPE)	2	4.5
▪ Work environment	4	9.1
▪ Seniority	2	4.5
▪ Gender	1	2.3
▪ Reporting	2	4.5
▪ Knowledge	1	2.3
▪ Work pressure, Stress	2	4.5
▪ Rewards and recognition	1	2.3
▪ Employee participation	3	7.0

The allocation of safety culture research to each industry, the aspects of safety culture, the objectives and the results of the corresponding studies are summarised in Figure 2.7. In Malaysia, healthcare, oil and gas and manufacturing have been the leading industries in safety culture research over the past 15 years. To better understand the target characteristics and importance of safety culture, this review paper classified the articles dealing with the aspect of a safety culture based on Cooper’s Reciprocal Model on safety culture. The model includes three aspects of safety culture, namely behavioural, psychological and situational context, which is supported by most academics and researchers involved in process improvement and accident prevention (Lund & Aarø, 2004). The analysis revealed that over the past decade, behavioural and situational aspects had been the most frequently studied characteristics of safety culture in Malaysia by researchers. This finding is in line with Cooper’s (2018) comprehensive research, which suggests that organisations should focus at least 80% of their efforts on improving and maturing situational and behavioural safety culture. Furthermore, the approach was supported by Ismail (2021), who discovered that the behavioural aspect has the greatest impact on building a positive safety culture, followed by the situational and psychological aspects. The results of this study also allow for the triangulation of perspectives related to safety culture within an organisation and across industries.

Industry		Safety Culture Aspect			Aim			Output																		
Category		A	B	C	X	Y	Z	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15	O16	O17	O18	O19
Aviation	8%	✓					✓	✓	✓	✓			✓	✓					✓			✓		✓		
Construction	8%			✓	✓								✓													
Education	8%	✓	✓	✓			✓		✓	✓						✓	✓	✓					✓			
Healthcare	30%	✓	✓	✓	✓		✓		✓	✓	✓								✓	✓	✓	✓		✓		✓
Manufacturing	15%	✓			✓			✓	✓									✓							✓	✓
Oil & Gas	23%	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓						✓							✓
Petrochemical	8%		✓				✓			✓																

Legends

Aim

X = Factor associated with safety culture
Y = Prediction of safety culture model framework
Z = Relationship between safety factors and safety culture

Safety Culture Aspect

A = Situational
B = Behavioural
C = Psychological

Output

O1 = Management Commitment, Management Practice, Organizational Support, Recruitment
O2 = Training, Competency
O3 = Communication
O4 = Work performance
O5 = Psychosocial
O6 = Employee Perception
O7 = Policy
O8 = Attitude, Behaviour
O9 = Influence of peer
O10 = Safety rule, Safety procedure
O11 = PPE
O12 = Work environment
O13 = Seniority
O14 = Gender
O15 = Reporting
O16 = Knowledge
O17 = Work pressure, Stress
O18 = Rewards, Recognition
O19 = Employee participation

Figure 2.7 Mapping of Safety Culture Research Between Industry, Safety Culture Aspects, Objectives and Outputs of Corresponding Studies in Malaysia.

In recent decades, research on safe work behaviour has become increasingly important in occupational health and safety (Zaira & Hadikusumo, 2017). In various industrial settings, several studies have attempted to determine the impact of workers' safe behaviour on occupational injuries (Varonen & Mattila, 2000 & Neal & Griffin, 2006). Numerous research findings have shown that unsafe work behaviours increase the risk of accidents and fatal injuries in workplaces (Choudhry, 2014). Other than that, research has shown that unsafe behaviour is responsible for approximately 80% of workplace incidents (Shin, 2015). According to Pareto's Law, only 20% of causes lead to 80% of outcomes. Applying this principle to accidents means that 20% of behaviours cause 80% of accidents. As of 2022, oil and gas, aviation, education and healthcare are the four industries that include situational, behavioural and psychological aspects when examining safety culture. It is imperative that the organisation considers all three aspects of safety culture, as the principle of the reciprocal model is to optimise the situation in order to optimise the behaviour. Furthermore, as the desired behaviours emerge, the various psychological elements will adapt and evolve towards a positive safety culture (Cooper, 2016).

Due to the Institute of Medicine (IOM) publication, awareness of patient safety within healthcare organisations has increased and is receiving more attention (Donaldson, 2000). This report has created the paradigm for a culture of safety where harmful incidents can be reported without blaming specific individuals and where lessons are learned from mistakes. One of the crucial components in improving patient safety is safety culture research, which is often conducted in the form of sampling in patient safety settings (Flin, 2007). Therefore, the number of safety culture research studies involving the healthcare setting is very high so that the organisation can understand the staff to improve safety culture and prevent incidents. The target population of this research includes doctors, nurses, pharmacists, clinical and non-clinical staff, and medical students working in the healthcare setting.

The Malaysian National OGSE Industry Blueprint (2021-2030) aims to create a "robust, resilient, and globally competitive" Malaysian oil and gas, services, and equipment sector that can improve national gross domestic product (GDP) growth, sector employment, export development, and fiscal contribution. However, these workers are exposed to high-risk activities as they work in hazardous environments with a significant likelihood of accidents or injuries (Bevilacqua *et al.*, 2020). Given the complexity and hazardous environment of oil and gas operations, minimising risks and preventing occupational accidents are important safety objectives (Ajmal *et al*., 2022; Berg *et al*., 2014). Studies have been conducted on health and safety in the oil and gas industry. However, despite the many fatalities, severe damages, and significant efforts to prevent such accidents, egregious disasters still occur in the industry, causing the loss of numerous priceless lives and resources (Hassan *et al*., 2020).

Several scientific studies on occupational accidents have focused on the manufacturing industry in Malaysia, as the work there is very dangerous, e.g., operating heavy machinery or coming into contact with chemicals (Saad *et al*., 2012, Rahman *et al*., 2014, Hee, 2014; Hui-Nee, 2014). According to the Ministry of Safety and Health in Malaysia, the number of accidents by sector is still dominated by manufacturing. A lack of safety culture is one of the reasons for the high number of accidents in the Malaysian manufacturing industry (Amirah *et al*., 2013). These findings are also confirmed by Ali et al. (2017), who suggests that many accidents in the manufacturing industry are due to violations of OSHA regulations and a failure to emphasise the importance of maintaining a safe work culture.

In this review, 19 elements of safety culture were identified from the positive predictive factors that practitioners and researchers could examine and apply to improve safety culture in the organisation. Training and competence (14%), communication (11.6%), and work environment (9.3%) were the crucial predictive elements influencing organisational safety culture across all seven sectors. Effective training is also key to changing a company's safety culture (Marquardt *et al*., 2021; Harvey et al., 2001), where increased communication at all levels of the organisation can improve safety culture and reduce incidents (Alsabri *et al*., 2021; Shuen & Wahab, 2016; Lyndon *et al*., 2015).

The research objectives of the articles studied are addressed in the three key contexts. The data indicate that the researchers' preferred and predominant study objective was the factors associated with a safety culture. The researchers specified variables as factors for the study, assuming that they would significantly impact the results. In examining indicators of safety culture, a wide range of factors have been discovered that can influence a safety culture (Flin *et al*., 2000, Guldenmund, 2000). However, there is still little consensus on the core factors of a safety culture. Most studies focus on identifying the core factors as well as the structure of these factors that make up safety culture and which factors are related to the safety culture of organisations. The relationships between safety variables and safety culture are also highlighted in safety culture studies, but very few studies have examined prediction as a research topic. The oil and gas industry seems to be the only industry that has predicted a major target of safety culture research in Malaysia.

The results of this research also present that the elements of safety culture vary across industries in Malaysia. For example, management practises, communication, job performance, employee perception and psychosocial aspects were the most important elements in the oil and gas industry, while in the health sector, work environment, seniority, gender, reporting, work stress, employee involvement, attitude, training and competence were the most important. Consequently, this result clearly demonstrates that each industry prefers different elements of safety culture to strengthen the organisation's culture. This is because different industries pose different industrial hazards and risks. In addition, safety cultures in organisations encompass both general and company-specific values and attitudes in managing the organisation's safety (Harvey *et al*., 2004). Consequently, this report clearly shows that different industries prefer different elements of safety culture to strengthen the organisation's culture.

In conclusion, establishing a universally applicable safety culture framework remains challenging because safety culture characteristics, organisational practices, operational risks, and regulatory requirements vary significantly across industries. Consequently, the safety culture elements and interventions that are effective in one industry may not be directly transferable to another. Future research should therefore expand across diverse industrial sectors to identify industry-specific safety culture indicators and determine how these elements influence safety performance within different operational contexts. Within the Malaysian context, further research is required to examine the interrelationships among psychological, behavioural, and situational safety culture dimensions across various industries. Such efforts would support the objectives of the Occupational Safety and Health Master Plan 2025 (OSHMP25) in promoting a proactive and preventive safety culture across all workplaces. In particular, the high-risk nature of the oil and gas industry necessitates safety management approaches that extend beyond regulatory compliance and traditional safety programmes. As demonstrated in this study, proactive safety culture plays a critical role in strengthening safety awareness, reducing unsafe behaviours, encouraging employee participation, and preventing workplace incidents before they occur. Therefore, organisations should move beyond compliance-driven practices and adopt proactive, evidence-based approaches that integrate safety culture principles into daily operations. The development of BOSCA represents one such initiative by translating validated safety culture dimensions into a practical digital intervention capable of supporting continuous safety engagement and improvement. Ultimately, fostering a proactive safety culture is essential for achieving sustainable safety performance, preventing major accidents, and creating safer work environments within the oil and gas industry and beyond.

2.6 Digital Interventions of Safety Culture: A Systematic Review of Mobile Applications[3]

2.6.1 Introduction

Unsafe behaviours remain a major contributor to accidents, injuries, and adverse events across high-risk sectors such as healthcare, construction, manufacturing, energy, and public health (Dodoo et al., 2019). Despite continuous improvements in engineering controls, regulations, and safety training, human behaviour continues to represent a critical vulnerability within safety systems (Leveson et al., 2017 and Ivensky, 2017). Behavioural safety, which encompasses individual actions, decision-making, and compliance with safety practices, is therefore increasingly recognised as a cornerstone of effective risk management (Aderamo et al., 2024). In complex and rapidly changing environments, traditional safety approaches that rely on periodic training or passive information dissemination are often insufficient to produce consistent and enduring behavioural change (Gielen et al., 2003 and Cooper, 2009).

The rapid global expansion of mobile technologies has introduced new possibilities for addressing behavioural safety challenges (Newaz et al., 2024). Mobile-based applications offer continuous accessibility, real-time feedback, and personalised interaction, enabling safety interventions to extend beyond conventional workplace or clinical settings (Egger et al., 2023). As a result, mobile applications have been increasingly adopted to support behaviour change, self-monitoring, reporting, decision-making, and communication in safety-critical contexts (Johson, 2017). Existing studies suggest that such technologies can enhance engagement, awareness, and adherence to recommended practices, particularly within health-related domains such as mental

[3] Hafiz Rahim, Rahmat Dapari, Mohd Ramadan Ab Hamid, Nazri Che Dom (2026). **Do Mobile Apps Make Work Safer? Evidence and Gaps in Behavioural Safety Across High-Risk Settings.** *Scientific Reports.* (Under Review)

health support, chronic disease management, pharmacovigilance, and public health surveillance (Okolo et al., 2024 and Ashraf et al., 2024). These developments have positioned mobile technologies as potentially scalable and cost-effective tools for influencing safety-related behaviours.

However, despite growing interest and adoption, current evidence remains fragmented and uneven. Many studies emphasise feasibility, usability, or short-term engagement rather than sustained behavioural change or tangible safety outcomes (Marquart et al., 2021, Schweitzer et al., 2024 and Breeman et al., 2021). Improvements in awareness or app usage are frequently treated as proxies for behavioural safety, even though their long-term impact on risk reduction is rarely demonstrated (Wirth et al., 2008). Furthermore, mobile safety interventions are often developed as stand-alone tools, with limited integration into organisational safety management systems, regulatory frameworks, or safety culture initiatives (Pupulidy, 2020). This raises concerns about whether observed behavioural changes can be maintained once initial motivation or novelty effects decline. These limitations are particularly important in high-risk industries and low- and middle-income settings, where unsafe behaviours are often shaped by structural constraints, limited resources, and organisational pressures. While mobile technologies are increasingly deployed in such contexts, the majority of published evidence originates from high-income countries and health-centred applications (Faizan et al., 2025). This imbalance restricts the generalisability of findings and limits understanding of how mobile-based safety solutions perform across diverse industrial, cultural, and regulatory environments. Consequently, there is a need to critically examine whether existing mobile interventions address the real determinants of unsafe behaviour in high-risk settings or primarily target individual-level factors in isolation.

To date, no comprehensive synthesis has systematically examined how mobile-based applications influence behavioural safety across different high-risk contexts, what types of applications are being developed, which behavioural mechanisms they target, and whether they achieve sustained safety benefits. Existing reviews tend to focus on specific technologies or sectors, offering limited insight into broader patterns of effectiveness, sustainability, and system integration. Addressing this gap is essential to inform future research, design, and policy directions. Therefore, the objective of this systematic literature review is to critically synthesise current evidence on mobile-based applications and digital technologies designed to influence behavioural safety in high-risk contexts. This review aims to clarify the types and functions of existing applications, examine the behavioural outcomes they target, assess their effectiveness in changing or reinforcing safe behaviours, and identify key gaps that must be addressed to advance system-integrated, outcome-oriented digital safety solutions.

2.6.2 Overview of Included Studies

This systematic literature review synthesised evidence from 22 peer-reviewed studies investigating the use of mobile-based applications and digital technologies to influence, reinforce, or support behavioural safety outcomes across a range of high-risk contexts (Table 2.6). The included studies spanned healthcare, public health, workplace health and safety, mental health, and regulatory or governance domains, reflecting the multidisciplinary nature of behavioural safety research and the expanding role of mobile technologies in risk-sensitive environments.

As summarised in Table 2.7, the geographical distribution of studies revealed a strong concentration in high-income countries, with the United States accounting for 28% of the evidence base, followed by the United Kingdom (20%), and multi-country European studies (20%). Together, these regions contributed over two-thirds of the included literature. In contrast, low- and middle-income countries (LMICs) were sparsely represented, with only isolated studies conducted in Uganda, China, and India. This imbalance highlights a significant limitation in contextual diversity, particularly given that many high-risk industries and occupational hazards are prevalent in LMIC settings. The under-representation of these contexts restricts the generalisability of current evidence and underscores the need for more geographically inclusive research. Regarding industry focus, the reviewed studies were predominantly situated within health-related domains. Mental health and suicide prevention applications constituted the largest single category (24%), reflecting the rapid growth of mobile interventions targeting psychological safety, emotional regulation, and crisis support. This was followed by digital health/eHealth and chronic disease management applications (each 16%), which primarily emphasised self-monitoring, adherence, and patient engagement as proxies for safety-related behaviours. In contrast, applications explicitly designed for workplace or occupational safety accounted for only 8% of the included studies (Table 2.7). This finding is notable given the established burden of accidents, injuries, and unsafe behaviours in high-risk industries such as construction, manufacturing, mining, and energy. The limited representation of occupational settings suggests that mobile-based safety technologies have been more extensively developed and evaluated within healthcare-oriented contexts than within traditional industrial safety environments.

Table 2.6
Summary of Evidence on Mobile-Based Applications and Digital Technologies Influencing Behavioural Safety Outcomes

Author & Year	Country	Industry	Type of Mobile App/ Technology	Purpose/ Function	Behavioural Outcomes Measured	Key Findings	Adoption / Usability Factors	Contribution to Behaviour Safety	Research Gaps Identified
Agarwal et al., 2025	USA	Digital mental health	Mental health apps (FASTER framework)	Develop a structured safety- and evidence-based app framework	Self-monitoring; coping behaviours; engagement.	Identified major gaps in safety, evidence, and crisis support.	Structured checklist improves evaluator consistency.	System-level behavioural safety evaluation.	Need broader validation and standardisation.
Kiguba et al., 2025	Uganda	Pharmaco vigilance	Med Safety ADR reporting app	Increase adverse drug reaction reporting via mobile technology	Reporting behaviour; engagement.	ADR reporting increased by 73% and sustained.	Low friction reporting improved adoption.	Improves safety reporting compliance.	Assess report quality and scalability.
Bucci et al., 2023	UK	Mental health	i-Minds digital intervention	Support emotional regulation and resilience in youth.	Mentalization; emotional regulation.	High acceptability and engagement.	Simple reflection prompts supported use.	Supports reflective behavioural coping.	Need powered RCTs.
Brown et al., 2024	Australia	Chronic disease	Digital lifestyle intervention	Assess feasibility of patient-selected digital lifestyle tools.	Engagement; adherence.	High uptake, declining engagement.	Wearables and reminders supported adherence.	Shows limits of sustained behaviour change.	Strategies for long-term engagement needed.
Puigdomènech et al., 2022	Spain	Digital health	EVALAPPS evaluation tool	Enable structured evaluation of obesity apps.	Critical appraisal behaviour.	Usable tool; evidence gaps in apps.	Clear criteria supported user evaluation.	Improves digital literacy and safe choice.	Full validation required.

Author & Year	Country	Industry	Type of Mobile App/ Technology	Purpose/ Function	Behavioural Outcomes Measured	Key Findings	Adoption / Usability Factors	Contribution to Behaviour Safety	Research Gaps Identified
Curran et al., 2019	Canada	Professional learning	Mobile learning tools	Explore adoption of mobile tools for learning.	Learning engagement.	High adoption driven by convenience.	Ease of access encouraged use.	Supports just-in-time decision behaviour.	Link to safety outcomes needed.
Bucci et al., 2025	UK	Mental health	i-Minds intervention	Assess feasibility for abuse recovery support.	Engagement; coping.	Acceptable digital delivery.	Youth-friendly design improved uptake.	Supports emotional safety.	Need larger trials.
Bernaerts et al., 2025	EU	Digital mental health	Adapted SAM & SAFE apps	Culturally adapt mental health apps.	Usability; engagement.	Improved comprehension and usability.	Co-design reduced misuse risk.	Improves safe engagement.	Effectiveness testing required.
Kitsiou et al., 2025	USA	Heart failure	iCardia4HF system	Improve HF self-care via tailored mHealth.	Self-care; self-efficacy.	High adherence; improved self-care.	Personalised feedback drove engagement.	Supports sustained self-management.	Long-term trials needed.
Wetzel et al., 2024	Germany	eHealth	Symptom checker apps	Identify predictors of app usage.	Health anxiety.	Hypochondria strongest predictor.	Psychological factors drive adoption.	Highlights behavioural risk.	Longitudinal studies needed.
Robbins et al., 2022	USA	Workplace health	Dayzz sleep app	Improve sleep and productivity.	Sleep duration; fatigue.	Improved sleep; reduced presenteeism.	High usability supported adoption.	Fatigue reduction supports safety.	Test in shift workers.
Knox et al., 2021	UK	COPD	COPD.Pal app	Support self-management and monitoring	Engagement; awareness.	High engagement; safe use.	Simple logging supported use.	Encourages early detection.	RCT required.
Fleming et al., 2020	EU/USA	Diabetes	Diabetes self-management apps	Review benefits, risks, regulation.	Self-monitoring; adherence.	Evidence limited; governance gaps.	Regulation affects adoption.	Highlights governance in safety.	Need long-term trials.

Author & Year	Country	Industry	Type of Mobile App/ Technology	Purpose/ Function	Behavioural Outcomes Measured	Key Findings	Adoption / Usability Factors	Contribution to Behaviour Safety	Research Gaps Identified
Khoong et al., 2020	USA	Health communication	Digital communication tools	Assess digital access disparities.	Communication behaviour.	Language/system type affected use.	Infrastructure enabled adoption.	Equity affects safety communication.	Intervention studies needed.
Rodriguez-Villa & Torous, 2019	USA/UK	Regulation	Self-certification framework	Propose dynamic digital health regulation.	Trust; adoption.	Transparency may improve safety.	Stakeholder involvement supports trust.	System-level behavioural safety.	Pilot testing required.
Milne-Ives et al., 2021	EU	Pharmacovigilance	Blockchain AE reporting	Improve trust in adverse event reporting.	Reporting behaviour.	DLT improves transparency potential.	Trust may drive reporting.	Supports honest safety reporting.	Usability trials needed.
Gilbert et al., 2020	EU/USA	Symptom triage	AI symptom checkers	Compare app accuracy vs GPs.	Urgency advice accuracy.	GPs outperformed apps.	Accuracy affects trust.	Unsafe advice risks behaviour.	Real-world studies needed.
Bruen et al., 2020	UK	Suicide prevention	Strength Within Me app	Assess feasibility in inpatient settings.	Disclosure; engagement.	High engagement; safe use.	Non-judgemental design aided use.	Improves psychological safety.	Longitudinal trials needed.
Krauss et al., 2025	EU	ILD	patientMpower + ASA-ILD	Enable home self-monitoring.	Adherence; engagement.	High adherence in pilot.	Clear workflow supported compliance.	Supports proactive risk monitoring.	Effectiveness outcomes needed.
Jiang & Zheng, 2023	China	Public health	Health Code apps	Assess privacy compliance.	Trust; consent behaviour.	Moderate compliance; weak sensitive PI protection.	Transparency affects trust.	Governance impacts behavioural safety.	User behaviour studies needed.

Author & Year	Country	Industry	Type of Mobile App/ Technology	Purpose/ Function	Behavioural Outcomes Measured	Key Findings	Adoption / Usability Factors	Contribution to Behaviour Safety	Research Gaps Identified
Smith et al., 2020	USA	Telepsychiatry	Telepsychiatry SOPs	Develop safety guidance for remote care.	Communication safety.	Clear SOPs improved safety.	Structured protocols aid adoption.	Procedural safety behaviours.	Effectiveness studies needed.
Verma & Mishra, 2020	India	COVID-19	COVID-19 mobile apps	Review mobile technology for detection and tracing.	Preventive behaviour.	Apps supported exposure awareness.	Government backing drove uptake.	Population-level safety behaviour.	Real-world effectiveness needed.

Note: This table synthesises findings from 22 peer-reviewed studies examining the role of mobile-based applications and digital health technologies in influencing, reinforcing, or supporting behavioural safety outcomes across healthcare, workplace, public health, and mental health contexts. The studies are organised by country, industry, application type, intended function, behavioural outcomes assessed, key findings, adoption and usability factors, contributions to behavioural safety, and identified research gaps, providing an integrated overview of current evidence and limitations in this field.

Overall, the characteristics of the included studies indicate a literature that is health-centric, geographically skewed towards high-income countries, and predominantly focused on individual-level behavioural outcomes. While these studies provide valuable insights into the feasibility and acceptability of mobile-based safety applications, they also reveal important gaps in sectoral coverage and contextual applicability that warrant further investigation.

Table 2.7
Quantitative Synthesis of Mobile-Based Safety Applications Across High-Risk Contexts (*n* = 22)

Domain	**Category**	**n**	**%**
Country / Region	USA	6	27.3
	UK	5	22.7
	EU (multi-country)	4	18.2
	Australia	1	4.5
	Canada	1	4.5
	Spain	1	4.5
	Germany	1	4.5
	China	1	4.5
	India	1	4.5
	Uganda	1	4.5
Industry	Mental health / suicide prevention	6	24.0
	Digital health / eHealth	4	16.0
	Chronic disease management	4	16.0
	Pharmacovigilance	3	12.0
	Workplace / occupational health	2	8.0
	Public health / COVID-19	2	8.0
	Regulation / governance	2	8.0
	Professional learning	1	4.0
	Telepsychiatry	1	4.0
Type of Mobile App / Technology	Behavioural intervention & wellbeing apps	6	27.3
	Self-monitoring & self-management apps	6	27.3
	Reporting & surveillance apps	4	18.2
	Decision-support / SOP / triage tools	3	13.6
	Evaluation & governance frameworks	3	13.6
Purpose / Function	Behaviour change & coping support	7	30.4
	Monitoring & early risk detection	6	26.1
	Safety reporting & disclosure	4	17.5
	Decision guidance & procedural safety	3	13.0
	Evaluation, regulation & trust-building	3	13.0
Behavioural Outcomes Measured*	Engagement / adherence	16	40.0
	Self-monitoring / awareness	9	22.5
	Reporting behaviour	5	12.5
	Trust / acceptance	5	12.5
	Emotional regulation / coping	4	10.0
	Fatigue / sleep-related behaviour	1	2.5
Key Findings	High usability / acceptability	14	33.3
	Improved engagement / adherence	11	26.2
	Improved reporting / disclosure	5	11.9

Domain	Category	n	%
	Governance and safety gaps identified	6	14.3
	Mixed or uncertain effectiveness	6	14.3
Adoption / Usability Factors	Ease of use / low-friction design	13	39.4
	Personalisation & feedback	6	18.2
	Trust, privacy & transparency	7	21.2
	Co-design / cultural adaptation	4	12.1
	Institutional / government support	3	9.1
Contribution to Behavioural Safety	Improves engagement & awareness	13	41.0
	Enhances reporting & compliance	6	19.4
	Supports psychological safety	5	16.1
	Enables system-level safety governance	4	12.9
	Reveals potential safety risks	3	9.7
Research Gaps Identified	Lack of long-term effectiveness data	15	28.3
	Absence of hard safety outcomes	13	24.5
	Limited scalability / generalisability	10	18.9
	Weak theoretical grounding	9	17.0
	Governance & regulatory uncertainty	6	11.3

Note: Percentages are calculated based on the total number of included studies (n = 22). Categories within several domains are not mutually exclusive, as individual studies may contribute to multiple classifications (e.g. more than one behavioural outcome, application function, adoption factor, or research gap). Consequently, the summed counts and percentages within these domains may exceed 22 and 100%, respectively. This approach reflects the multidimensional nature of mobile-based safety applications and allows a more comprehensive representation of their characteristics, functions, and impacts across high-risk contexts.

2.6.3 Types of Mobile-based Safety Applications

Five major categories of mobile-based safety applications were identified across the included studies (Figure 2.8), reflecting different conceptual approaches to influencing behavioural safety in high-risk contexts. The most prevalent category comprised behavioural intervention and wellbeing applications, accounting for 28% of the reviewed studies. These applications were primarily designed to promote safer behaviours through psychological or behavioural mechanisms, such as emotional regulation, coping strategies, resilience building, and reflective self-assessment. They were commonly deployed in mental health and wellbeing contexts and focused on modifying individual attitudes and behaviours that indirectly contribute to safety, particularly psychological safety and risk awareness.

The second largest category consisted of self-monitoring and self-management applications (24%). These tools enabled users to actively track symptoms, behaviours, or risk indicators, often coupled with feedback, reminders, or personalised insights. Such applications were frequently applied in chronic disease management and digital health settings, where ongoing monitoring and user engagement are central to preventing deterioration or unsafe outcomes. From a behavioural safety perspective, these applications emphasised situational awareness and personal accountability, reinforcing safe practices through continuous self-observation. Reporting and surveillance applications represented 16% of the included studies and were largely oriented towards organisational safety processes. This category encompassed pharmacovigilance systems, adverse event reporting platforms, and other disclosure-focused technologies designed to lower reporting barriers and improve compliance. By facilitating timely and low-friction reporting, these applications contributed to behavioural safety at the organisational level by strengthening feedback loops, enhancing transparency, and supporting proactive risk identification.

An equivalent proportion of studies (16%) examined decision-support, standard operating procedure (SOP), and triage tools. These applications were intended to guide users through structured decision-making processes, often by providing rule-based recommendations, urgency assessments, or procedural guidance. Rather than targeting behaviour change directly, these tools supported procedural safety behaviours, helping users align actions with established safety protocols and reducing reliance on subjective judgement in high-risk situations. Finally, evaluation and governance-oriented frameworks also accounted for 16% of the reviewed applications. These technologies focused on system-level functions, including application evaluation, regulatory compliance, transparency, and trust building. Rather than intervening at the point of individual behaviour, governance-oriented applications aimed to shape the broader safety ecosystem by improving standards, accountability, and institutional oversight. Their contribution to behavioural safety was therefore indirect but potentially more sustainable, as they addressed structural conditions that influence safe behaviour.

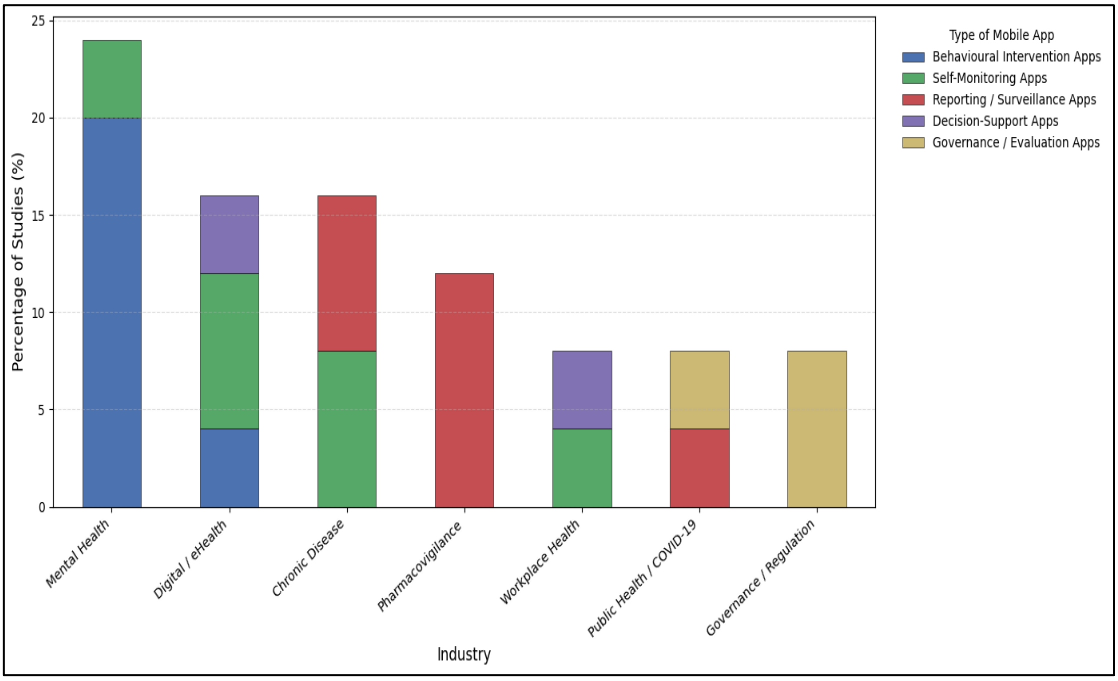

Figure 2.8 Distribution of Mobile-Based Safety Application Types. Showing the proportional contribution (%) of behavioural intervention, self-monitoring, reporting and surveillance, decision-support and governance-oriented applications (N = 22).

2.6.4 Intended Functions and Behavioural Outcomes

The primary purposes of mobile-based safety applications clustered around behaviour change and coping support (32%) and monitoring and early risk detection (24%), as shown in Table 2.5. Fewer studies focused on safety reporting and disclosure (16%), decision guidance and procedural safety (16%), or evaluation, regulation, and trust-building (12%). Behavioural outcomes assessed across studies were predominantly process-oriented rather than outcome-oriented. Engagement and adherence were measured in 72% of studies, followed by self-monitoring and awareness (40%), while reporting behaviour and trust or acceptance were each examined in only 20% of the literature. The relationship between application type and targeted behavioural outcomes is illustrated in Figure 2.9, which shows that behavioural intervention and self-monitoring applications primarily addressed engagement and awareness, whereas reporting and governance tools were more closely linked to disclosure and compliance-related behaviours.

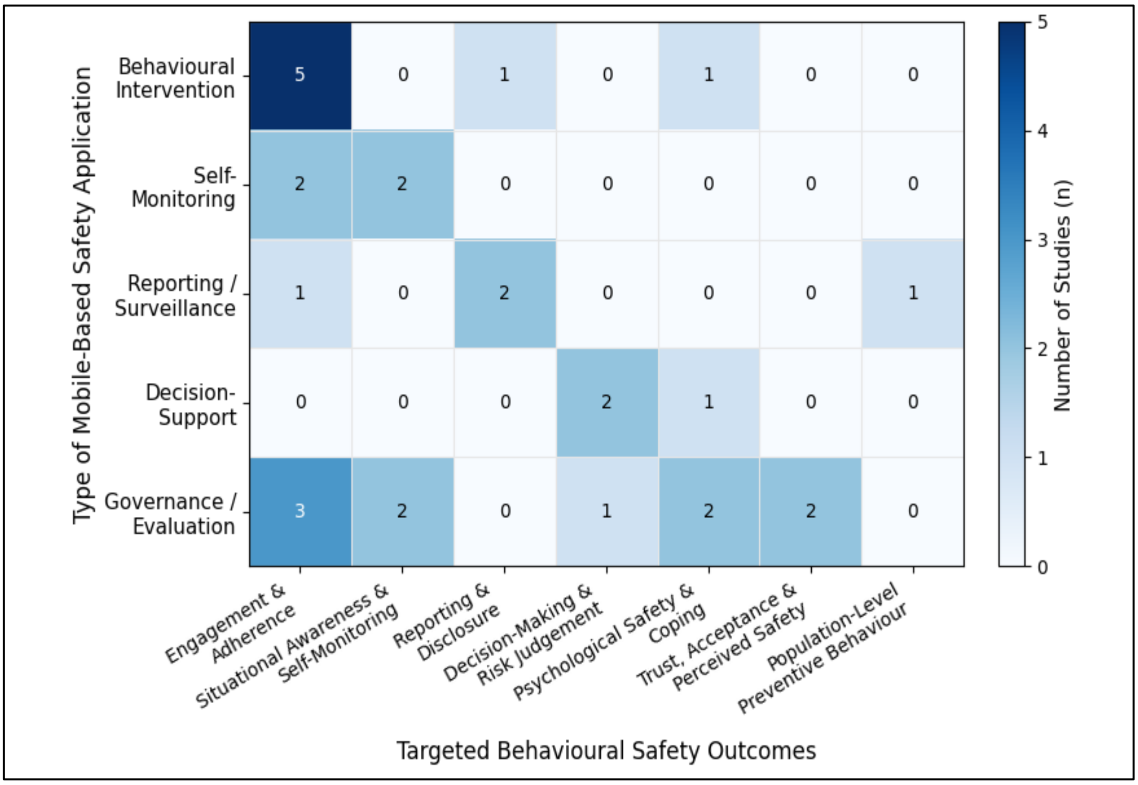

Figure 2.9 Heatmap Illustrating the Distribution of Behavioural Safety Outcomes Targeted by Different Types of Mobile-Based Safety Applications. Numbers within cells indicate the number of studies per application–outcome combination, while blue shading reflects relative frequency across categories (n = 22).

2.6.5 Effectiveness of Applications in Changing or Reinforcing Behaviour

The effectiveness of mobile-based safety applications in influencing behavioural safety outcomes exhibited clear heterogeneity across application types, revealing important distinctions between short-term behavioural responsiveness and sustained safety impact (Figure 2.10). Overall, the evidence base was dominated by studies reporting positive short-term behavioural change (E1), particularly among behavioural intervention and self-monitoring applications. These technologies consistently demonstrated the capacity to rapidly enhance engagement, awareness, and self-regulatory behaviours, suggesting that mobile platforms are effective catalysts for initial behaviour activation in high-risk contexts.

However, progression from short-term change to sustained behavioural reinforcement (E2) was comparatively rare. Where sustained effects were observed, they were predominantly associated with applications that extended beyond stand-alone user interaction by incorporating structured feedback loops, integration with organisational systems, or governance-oriented features. These findings indicate that durability of behaviour change is less dependent on application novelty or usability alone, and more strongly linked to embedded reinforcement mechanisms that align individual behaviour with institutional processes and accountability structures. Evidence of direct safety-related impact (E3) such as demonstrable improvements in reporting compliance, reductions in fatigue-related behaviours, or enhanced procedural adherence was limited to a small subset of studies. Importantly, these impacts were most evident in reporting, surveillance, and system-supported applications, reinforcing the notion that behavioural safety gains are more likely to translate into tangible safety outcomes when mobile technologies are embedded within formal safety management systems rather than deployed as isolated behavioural tools.

A notable proportion of studies were classified as inconclusive or mixed in effectiveness (E4), reflecting variability in study design, outcome measurement, and follow-up duration. In several cases, positive engagement outcomes did not translate into measurable behavioural reinforcement or safety-related change, highlighting a disconnect between use and impact. Additionally, a subset of studies did not formally evaluate effectiveness (E0), focusing instead on feasibility, usability, or acceptability metrics. While such outcomes are essential for early-stage development, their predominance underscores the immaturity of the evidence base with respect to behavioural safety effectiveness. Collectively, the distribution of effectiveness categories in Figure 2.10 demonstrates that mobile-based safety applications are highly capable of initiating behaviour change, yet far less successful in sustaining or operationalising these changes into measurable safety outcomes. This pattern underscores a critical gap between behavioural engagement and safety performance, signalling the need for future interventions to move beyond short-term behavioural influence towards system-integrated, outcome-driven safety solutions.

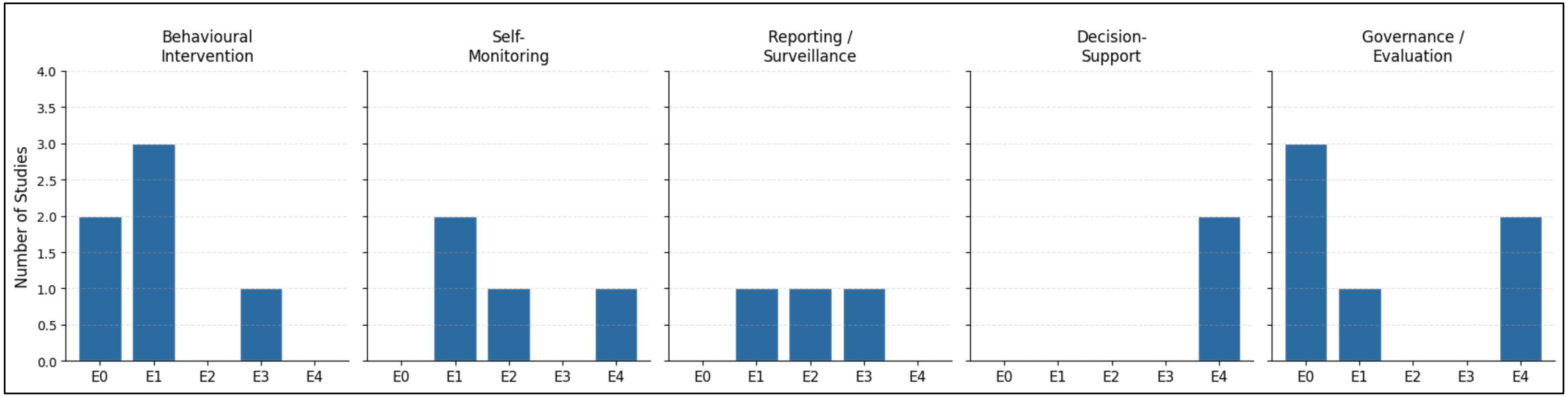

Figure 2.10 Effectiveness of Mobile-Based Safety Applications in Changing or Reinforcing Safe Behaviours, Stratified by Application Type. Effectiveness categories are coded as E0 (no effectiveness assessed), E1 (positive short-term behavioural change), E2 (sustained behavioural reinforcement), E3 (safety-related impact) and E4 (inconclusive or mixed evidence). Bars represent the number of studies within each category (n = 22).

2.6.6 Sustainability of Behavioural Effects

The temporal sustainability of behavioural effects is summarised in Figure 2.11. Most behavioural intervention and self-monitoring applications demonstrated effects limited to the immediate (≤8 weeks) or short-term (≤6 months) periods, with diminishing impact over time. In contrast, governance and evaluation-oriented applications showed comparatively stronger long-term (>6 months) behavioural effects, likely due to their integration within organisational or regulatory systems rather than reliance on individual motivation alone. These patterns suggest that stand-alone mobile interventions are vulnerable to engagement decay, whereas system-embedded tools may offer more durable behavioural safety benefits.

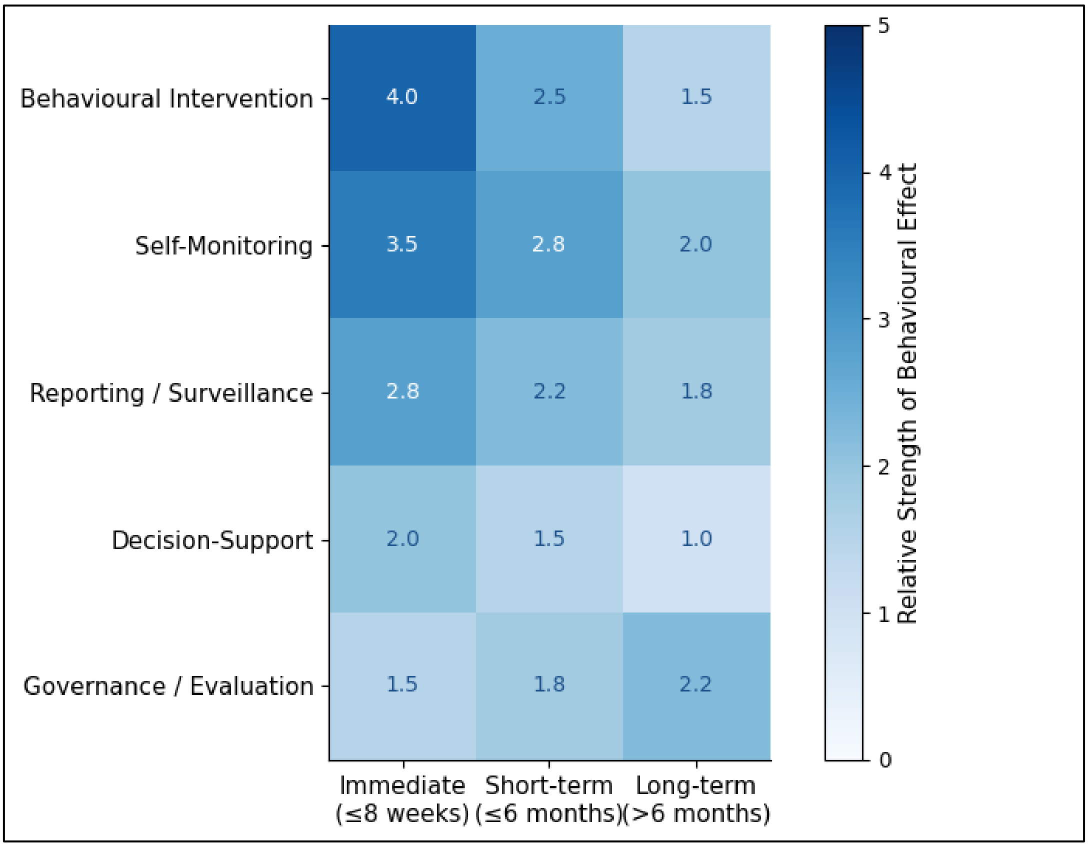

Figure 2.11 Heatmap Illustrating the Sustainability of Behavioural Effects of Mobile-Based Safety Applications Across Time. Rows represent application types and columns indicate the duration of behavioural effects (immediate ≤8 weeks, short-term ≤6 months, and long-term >6 months). Cell values and colour intensity denote the relative strength of behavioural effects, highlighting attenuation over time for most application types and comparatively stronger long-term sustainability for governance and evaluation applications.

2.6.7 Adoption, Usability and Engagement Factors

Factors influencing adoption, usability, and sustained engagement are synthesised in Table 2.8. Application design and functionality, particularly ease of use and low-friction interfaces, were the most frequently reported determinants of both adoption and usability. Ethical, privacy, and trust-related factors also played a significant role, particularly in applications involving surveillance, reporting, or sensitive personal data. In contrast, sustained engagement mechanisms were rarely addressed explicitly, with only one study identifying organisational or contextual supports capable of maintaining long-term use. This imbalance highlights a critical gap between initial uptake and sustained behavioural integration.

Table 2.8
Factors Influencing the Adoption, Usability, and Sustained Engagement of Mobile-Based Safety Applications

Factor Domain	**Adoption (n)**	**Usability (n)**	**Sustained Engagement (n)**
Individual-level factors	0	0	0
App design & functionality	5	5	0
Organisational & contextual factors	0	0	1
Ethical, privacy & trust factors	4	4	0
Engagement & sustainability mechanisms	1	1	0

Note: This table summarises the frequency of thematic factor domains influencing adoption, usability, and sustained engagement of mobile-based safety applications identified through qualitative synthesis of the included studies (*n*=22). Counts represent the number of studies reporting at least one factor within each domain. Adoption- and usability-related factors were derived from reported adoption and usability considerations, while sustained engagement factors were identified from study limitations and long-term usage discussions. Frequencies reflect the presence of reported factors rather than their relative strength or effect size.

2.6.8 Discussion

The findings of this systematic literature review reinforce a growing consensus in the digital safety and health literature that mobile-based applications are highly effective in activating safety-related behaviours, yet considerably less effective in sustaining those behaviours over time or translating them into measurable safety performance outcomes. Prior studies in digital health and occupational safety have similarly reported that mobile interventions often generate rapid improvements in engagement, awareness, and self-regulation, particularly during early phases of implementation. However, these gains frequently attenuate once novelty effects diminish or user motivation declines, a pattern widely observed in behaviour change technologies across health and safety domains. This review extends previous work by demonstrating that short-term behavioural responsiveness alone is an insufficient indicator of behavioural safety effectiveness. While earlier studies have emphasised usability and acceptability as key success metrics, the present synthesis shows that engagement without reinforcement rarely evolves into sustained safe behaviour. This aligns with established safety science theories, which emphasise that behaviour change must be continuously reinforced through environmental cues, organisational norms, and accountability mechanisms to remain stable.

A dominant theme emerging from the reviewed literature is the individual-centric orientation of most mobile-based safety applications. Many interventions are grounded in psychological or self-regulatory frameworks that prioritise awareness, reflection, and personal responsibility. Previous research in behavioural safety has long acknowledged the value of individual-level interventions, particularly for enhancing psychological safety, coping capacity, and risk perception. However, the same body of literature also cautions that over-reliance on self-regulation places an unrealistic burden on individuals, especially in high-risk environments characterised by time pressure, fatigue, and competing demands. The present review supports this critique by showing that applications focused primarily on individual behaviour modification tend to achieve behavioural initiation rather than behavioural institutionalisation. Earlier occupational safety studies have demonstrated that unsafe behaviours are rarely the result of individual deficits alone, but rather emerge from interactions between workers, systems, and organisational cultures. Mobile applications that fail to engage with these broader determinants are therefore structurally constrained in their capacity to deliver lasting safety improvements.

Consistent with prior safety management and human factors research, this review found that applications integrated with organisational systems, such as reporting platforms, procedural guidance, or governance frameworks, were more likely to demonstrate sustained behavioural effects and observable safety-related impacts. Previous studies in pharmacovigilance, incident reporting, and fatigue management have shown that digital tools are most effective when they are embedded within formal safety management systems, where behaviour is reinforced through feedback, oversight, and institutional learning. This finding resonates with the safety culture literature, which emphasises that safe behaviour is shaped not only by individual intentions but also by shared norms, leadership commitment, and organisational learning mechanisms. Mobile technologies that function as extensions of these systems can reinforce desired behaviours through consistent cues and consequences, whereas stand-alone applications risk becoming peripheral or discretionary tools with diminishing influence over time.

A critical insight from this review is the misalignment between commonly assessed outcomes and meaningful safety impact. The predominance of engagement, adherence, and awareness measures reflects broader trends in digital intervention research, where behavioural proxies are often used in place of direct safety indicators. While these measures are valuable for early-stage evaluation, previous scholars have cautioned that engagement does not equate to effectiveness, particularly in safety-critical settings. The limited assessment of hard safety outcomes identified in this review mirrors gaps highlighted in earlier systematic reviews of digital health and occupational safety technologies. Without robust evaluation of outcomes, such as incident rates, reporting quality, or procedural compliance, it remains difficult to determine whether mobile-based interventions genuinely enhance behavioural safety or merely improve interaction with technology. This review therefore reinforces calls from prior studies for outcome-driven evaluation frameworks that explicitly link behavioural mechanisms to safety performance.

The concentration of evidence in high-income, healthcare-oriented contexts reflects broader structural biases in digital safety research. Previous scholars have noted that technological innovation and evaluation tend to be concentrated in settings with strong research infrastructure, regulatory clarity, and digital maturity. However, many high-risk industries operate in low- and middle-income contexts where safety challenges are more pronounced and resources more constrained. The limited representation of such settings in the reviewed literature constrains the generalisability of existing findings and raises concerns about contextual transferability. Prior research has shown that cultural norms, regulatory environments, and organisational structures significantly influence how safety technologies are adopted and used. The present review underscores the need for future studies to engage more deeply with diverse industrial and socioeconomic contexts, particularly where mobile technologies may offer the greatest marginal safety benefit.

Synthesising these findings with existing literature suggests that the next phase of mobile-based safety innovation must move beyond behavioural nudging and individual engagement, towards system-integrated, theory-informed safety interventions. Design approaches should explicitly incorporate principles from safety culture, human factors, and organisational psychology, ensuring that digital tools reinforce, not replace, existing safety structures. From a research perspective, future studies should prioritise longitudinal designs, stronger theoretical grounding, and explicit assessment of safety outcomes. Importantly, researchers should examine how mobile applications interact with organisational context, leadership, and policy environments, rather than treating behaviour as an isolated individual phenomenon.

In summary, when situated within the broader behavioural safety literature, the findings of this review indicate that mobile-based applications are necessary but not sufficient tools for improving behavioural safety in high-risk contexts. They excel at initiating awareness and engagement, but their long-term effectiveness depends on system-level integration, organisational reinforcement, and outcome-oriented evaluation. Addressing these challenges represents a critical opportunity to advance both the science and practice of digital behavioural safety.

2.7 Chapter Summary and Research Gap

The literature review demonstrates that safety culture has been extensively studied across various industries, with psychological, behavioural, and situational dimensions consistently identified as important determinants of safety performance. Similarly, mobile-based safety applications have shown potential in influencing behavioural safety outcomes through reporting, monitoring, training, and communication functions. However, existing studies reveal three important gaps. First, limited research has systematically integrated safety culture dimensions into a digital intervention framework. Second, most safety applications focus on compliance and monitoring rather than strengthening proactive safety culture. Third, few studies have employed empirical methods such as AHP and SEM to identify, prioritise, and validate safety culture dimensions before translating them into a digital application. Therefore, this study addresses these gaps through the development and evaluation of BOSCA, an evidence-based safety culture mobile application for the Malaysian oil and gas industry.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Description of the Research

The research employed a multi-phase methodology to examine, validate, and digitally transform safety culture practices in the Malaysian oil and gas industry. It began with a systematic literature review to map current socio-technical dimensions of safety culture, focusing on human, behavioural, organisational, and technological factors. Building on these findings, the study advanced into the development and validation of a structured questionnaire, incorporating expert panels, content validity assessment, reliability testing, and the Analytic Hierarchy Process (AHP) to prioritise key safety elements. In the next phase, a cross-sectional stakeholder analysis was conducted to decode preferences and influential factors across psychological, behavioural, and situational dimensions. The study then extended these findings into a structural equation modelling (SEM) framework to examine the hierarchical relationships among safety constructs and identify demographic and organisational predictors of safety outcomes. Finally, the research translated validated behavioural components into a digital intervention, developing and refining the Behavioural Occupational Safety Culture Application (BOSCA) through user-centred design, expert validation, and iterative improvements. Collectively, these phases provided a comprehensive pathway from evidence synthesis to instrument development, empirical modelling, and practical digital application to strengthen safety culture within the oil and gas industry.

Study populations and sample sizes varied according to the objectives and requirements of each research phase. For the questionnaire development phase, five respondents participated in the face validity assessment, while seven subject matter experts were involved in the content validity assessment using the Content Validity Index (CVI) and Content Validity Ratio (CVR). The reliability analysis was conducted using a pilot sample of respondent’s representative of the target population. For the prioritisation phase, 40 experts representing academia, industry practitioners, management personnel, and regulatory authorities participated in the Analytic

Hierarchy Process (AHP) analysis. The Structural Equation Modelling (SEM) phase involved respondents from Malaysian industries to validate the relationships among the psychological, behavioural, and situational safety culture dimensions. For the BOSCA validation phase, experts and industry practitioners were recruited to evaluate the application's content, interface design, interactivity, and instructional strategies using the Fuzzy Delphi Technique (FDT) and user acceptance assessment. The sample sizes for each phase were determined based on the methodological requirements and recommendations reported in the literature to ensure the validity and reliability of the findings.

3.2 Detailed Description of the Research Architecture

The research architecture for this study was systematically organised into six sequential phases, as summarised in Table 3.1, each representing a distinct methodological component that contributed to the overall development, validation, and digital transformation of safety culture practices in the Malaysian oil and gas industry. This structured approach ensured methodological coherence, analytical depth, and alignment between evidence synthesis, empirical investigation, and technological innovation. Phase 1 employed a Systematic Literature Review (SLR) guided by the PRISMA framework to establish a foundational understanding of safety culture determinants within the oil and gas sector. This phase synthesised peer-reviewed studies from major databases between 2013 and 2024, identifying the key behavioural, psychological, situational, and technological factors influencing safety outcomes. The resulting thematic structure comprising three main themes and eighteen subthemes served as the conceptual backbone for subsequent phases of the study. Building on this foundation, Phase 2 focused on the development and validation of a structured questionnaire designed to measure stakeholder preferences towards safety culture elements. As highlighted in the table, this phase integrated expert-driven methods, including face validity, Content Validity Index (CVI), Content Validity Ratio (CVR), and reliability testing using Cronbach’s alpha. A total of 40 participants contributed to the development process, while expert panels ensured the content rigor and psychometric soundness of the resulting 52-item instrument.

Phase 3 transitioned into empirical prioritisation of safety culture elements using a cross-sectional study involving 40 subject matter experts (SMEs). Through the

Analytic Hierarchy Process (AHP), stakeholder judgements on psychological, situational, and behavioural elements were systematically analysed to identify the most influential components. Consistent with earlier evidence, behavioural factors emerged as the top-ranked drivers of safety culture maturity, reinforcing the theoretical emphasis established in Phase 1. To examine how these safety constructs interact within organisational settings, Phase 4 applied a cross-sectional analytical approach incorporating regression modelling, Confirmatory Factor Analysis (CFA), and Structural Equation Modelling (SEM). As reflected in the table, this phase investigated the hierarchical relationships among psychological, behavioural, and situational constructs while also identifying demographic and organisational predictors of safety outcomes. This provided robust empirical validation of the higher-order safety culture model. The selection of CVR, EFA, AHP, FDT, and SEM was guided by the objectives of the study and established methodological practices. CVR was employed to evaluate content relevance and essentiality, EFA to explore the underlying factor structure, AHP to prioritise safety culture dimensions based on expert judgement, FDT to establish expert consensus, and SEM to validate the relationships among safety culture constructs. The acceptance criteria and statistical thresholds adopted in this study were based on recommendations from previous methodological literature.

The findings from Phases 1–4 were subsequently translated into a digital intervention in Phase 5, where the Behavioural Occupational Safety Culture Application (BOSCA) was designed and developed. As summarised in Table 3.1, this phase utilised a Design and Development Research (DDR) framework, incorporating needs assessment, interface prototyping, system architecture development, UX/ UI design principles, and cross-platform implementation using Flutter, Vue.js, Firebase, and Supabase. This phase operationalised the prioritised behavioural elements into a fully structured digital safety culture tool. Finally, Phase 6 involved a rigorous validation of the BOSCA application using the Fuzzy Delphi Technique (FDT). As indicated in the table, 15 multidisciplinary OSH experts evaluated BOSCA based on content accuracy, interface design, interactivity, and instructional strategies. The analysis confirmed strong expert consensus across all evaluated components, providing evidence of usability, practical relevance, and pedagogical soundness.

Overall, the research architecture presented in Table 3.1 demonstrates a highly integrated and progressive methodological design that moves from evidence synthesis to instrument development, empirical testing, and finally the creation and expert validation of a digital behavioural safety culture framework. This sequential structure ensures that each research phase directly informs the next, resulting in a theory-driven, empirically grounded, and technologically advanced contribution to safety culture advancement in the oil and gas industry.

Table 3.1
Detailed Research Architecture Integrating Systematic Review, Instrument Development, Modelling and Digital Application

Phase	Design / Approach	Purpose / Focus	Participants / Data Sources	Main Methods & Procedures	Key Outputs
Phase 1 Systematic Review on Safety Culture	Systematic Literature Review (PRISMA)	To synthesise global evidence on psychological, behavioural, situational, and technological determinants of safety culture in oil & gas	Peer-reviewed articles (2013–2024) from Scopus, WoS, SpringerLink	PRISMA screening, PICOT scoping, quality appraisal, thematic analysis (Braun & Clarke)	33 high-quality studies, 3 major themes, 18 subthemes
Phase 2 Questionnaire Development & Validation	Instrument Development + Expert Validation	To construct and validate a safety culture preference questionnaire using AHP	40 participants for development; 5 experts for face validity; 7 experts for CVI/CVR	Literature extraction, AHP structuring, face validity, CVI, CVR, Cronbach's alpha	Validated 52-item questionnaire with strong content validity and reliability
Phase 3 Stakeholder Prioritisation of Safety Culture	Cross-sectional Study	To determine stakeholder preferences across psychological, behavioural, and situational elements	40 subject matter experts (SMEs) from regulators, industry, academia, practitioners	AHP pairwise comparison, stakeholder sampling (purposive + snowball), matrix construction, consistency ratio	Priority ranking of 18 safety culture sub-elements; behavioural elements highest
Phase 4 Structural Modelling of Safety Culture	Cross-sectional Analytical + SEM	To test relationships among safety culture constructs and identify demographic predictors	Workers across oil & gas, manufacturing, services sectors	Regression modelling, CFA, SEM (maximum likelihood), construct reliability & AVE testing	Validated higher-order model of safety culture; significant predictors identified
Phase 5 BOSCA Application Development	Design & Development Research (DDR)	To design a digital behavioural safety culture application (mobile/PWA)	15 industry practitioners; interface prototypes, system requirements	Needs analysis, module mapping, UI/UX design, Figma prototyping, Flutter/Vue.js development, Firebase/Supabase backend	BOSCA application prototype (modules: audit, training, communication, competency)
Phase 6 BOSCA Validation	Design & Development Research + Fuzzy Delphi	To validate BOSCA's content, interface, interactivity, and instructional strategy	15 multidisciplinary experts from OSH domain	Fuzzy Delphi Technique (threshold $d \leq 0.2$, consensus $\geq 75\%$), defuzzification, UX and instructional alignment	Verified BOSCA usability, content accuracy, and digital pedagogical alignment

Note: This table summarises the methodological architecture of the study across six sequential phases. It outlines the research design, purpose, participants or data sources, analytical procedures, and key outputs for each phase. The table is intended to help readers understand how the study progresses logically from evidence synthesis to empirical validation and finally to the development and expert evaluation of the BOSCA digital application.

3.3 Research Methodology

3.3.1 Phase 1: A Systematic Exploration of Safety Culture Transformation in the Oil and Gas

a) Study Design and Methodological Orientation

This study adopted a systematic literature review (SLR) approach to identify, evaluate, and synthesize research related to safety culture within the oil and gas industry, emphasizing how human, organisational, and technological factors interact in shaping safety management systems. The design was grounded in a socio-technical perspective, recognising that safety outcomes in high-risk industries emerge from the interplay between technological infrastructures, human behaviours and institutional frameworks. This orientation aligns with the journal's focus on how technological change interacts with social and policy dimensions (Bisbey et al.,2021 and Nævestad et al., 2021).

To ensure methodological rigor, the study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides structured procedures for literature identification, screening, eligibility assessment, and inclusion. PRISMA was chosen for its cross-disciplinary credibility and transparent standards for replicable research synthesis (Adaku et al., 2021 and Shaffril et al., 2019). It has been successfully applied in diverse fields, including safety management, healthcare (Danielli et al., 2021 and Vasquez et al., 2019), and technology governance (Cubric, 2020). This framework ensured that every methodological step from literature search to thematic synthesis was systematically documented and replicable.

b) Scope and Analytical Framework (Modified PICOT)

The scope of this review was defined using a modified PICOT framework adapted to suit socio-technical research contexts. The *Population (P)* included individuals, organisations, and facilities operating within the global oil and gas industry, where automation and digital technologies have become integral to safety operations. The *Intervention or Exposure (I)* focused on safety culture factors, including leadership, worker engagement, technological safety tools, and regulatory mechanisms that influence behaviour and performance. Since the study aimed to explore conceptual relationships rather than compare interventions, the *Comparator (C)* component was omitted. The *Outcome (O)* centred on identifying key behavioural, situational, psychological, and technological determinants shaping safety culture. The *Timeframe (T)* encompassed the period 2013–2024, reflecting an era of industrial digitalization and the increasing use of AI-assisted safety monitoring, automation, and predictive analytics (Al-Rbeawi, 2023). This temporal framing captured the evolution of safety management in response to Industry 4.0 transformations.

c) Literature Search and Data Sources

A comprehensive search strategy was implemented across Scopus, Web of Science (WoS), and SpringerLink, chosen for their extensive coverage of peer-reviewed studies across engineering, technology management, and social sciences. The search terms combined the keywords "*Oil and Gas*" AND "*Safety Culture*", ensuring inclusion of studies addressing safety practices from both technological and behavioural perspectives. The search was limited to English-language journal articles published between 2013 and 2024 to coincide with a decade of rapid digital and organisational transformation in the oil and gas sector. Duplicates were removed, and the remaining records were screened in three stages; title, abstract, and full-text review based on predefined inclusion and exclusion criteria (Kitchenham, 2004 and Cook et al., 1995). This procedure enhanced both transparency and comprehensiveness, ensuring a balanced representation of literature linking technological innovation to human-centred safety practices.

d) Inclusion, Exclusion, and Eligibility Criteria

Inclusion criteria prioritised studies that explicitly investigated safety culture or its influencing factors; behavioural, situational, psychological, or technological within oil and gas operations. Only empirical research (quantitative, qualitative, or mixed-method) published in peer-reviewed journals was included. Studies integrating digital safety systems, automation, or AI-based monitoring were given particular attention for their relevance to socio-technical adaptation. Exclusion criteria eliminated conference abstracts, grey literature, non-English sources, and papers unrelated to safety culture or focused solely on environmental, economic, or lifecycle analyses. This ensured that the review concentrated exclusively on evidence pertaining to human-technology interactions and organisational adaptation in safety contexts. Following the screening process, 33 studies were retained for full analysis. These works collectively represent global perspectives on how safety culture evolves under technological and operational change. Review articles and book chapters were excluded because they do not provide primary empirical data required for thematic synthesis and subsequent framework development. As this study aimed to identify and analyse evidence-based safety culture dimensions and elements from original research, only primary empirical studies were included to ensure the reliability and validity of the extracted findings.

e) Quality Assessment

The methodological quality of each study was evaluated using a 12-items assessment matrix adapted from established primary research appraisal frameworks (Kitchenham, 2004). Each study was rated against parameters such as clarity of objectives, methodological rigor, sampling strategy, control of confounders, and transparency in reporting. Scores were assigned as “Yes” = 2, “Partial” = 1, or “No” = 0. To enhance objectivity, two independent reviewers conducted the assessment, with discrepancies resolved through consensus or consultation with a third reviewer. Studies achieving a total quality score of 75 % or higher were classified as *high quality*. This procedure ensured that only robust and methodologically sound research contributed to the synthesis, thereby reinforcing the validity of conclusions drawn about the socio-technical dimensions of safety culture.

To ensure the methodological rigour and credibility of the selected studies, a quality assessment was conducted using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists. The checklist selected depended on the design of each included study. The assessment aimed to evaluate the methodological quality, risk of bias, and reliability of the evidence prior to data synthesis. For cross-sectional studies, the JBI checklist assessed: (i) clearly defined inclusion criteria, (ii) detailed description of study participants and setting, (iii) valid and reliable measurement of exposure, (iv) use of objective and standard criteria for outcome measurement, (v) identification of confounding factors, (vi) strategies to address confounding factors, (vii) valid and reliable outcome measurement, and (viii) appropriate statistical analysis. For quasi-experimental studies, the assessment included: (i) clarity of cause-and-effect relationship, (ii) similarity of participants, (iii) consistency of treatment and control conditions, (iv) existence of a control group, (v) multiple outcome measurements before and after intervention, (vi) completeness of follow-up, (vii) reliability of outcome measurement, and (viii) appropriateness of statistical analysis. For cohort studies, the criteria included: (i) similarity of groups, (ii) valid exposure measurement, (iii) identification and management of confounding factors, (iv) valid outcome measurement, (v) adequate follow-up period, (vi) completeness of follow-up, and (vii) appropriate statistical analysis. Each criterion was rated as “Yes”, “No”, “Unclear”, or “Not Applicable”. Studies that met the majority of the quality criteria were considered suitable for inclusion in the review and subsequent thematic analysis.

f) Data Synthesis and Thematic Analysis

The final data synthesis process aimed to identify recurring patterns and cross-cutting themes describing how behavioural, situational, and psychological factors interact with technological advancements in shaping safety culture. The Braun and Clarke (2006) six-phase approach to thematic analysis guided this process: familiarization with the data, generation of initial codes, identification of themes, theme review, definition, and reporting. Through iterative analysis, three overarching themes; behavioural, situational, and psychological emerged, supported by 18 subthemes capturing specific influences such as leadership style, worker communication, technological adaptation, and policy enforcement. The analysis highlighted how digitalization, automation, and AI-enabled monitoring systems reshape traditional notions of safety behaviour, risk perception, and compliance. A PRISMA flow diagram (Figure 3.1) illustrates the identification, screening, and inclusion process across databases.

Following data extraction, a manual thematic analysis was conducted to synthesise the findings from the selected studies. Relevant information was reviewed and coded based on recurring concepts related to safety culture. Similar codes were subsequently categorised and grouped into themes and sub-themes through an iterative comparison process. The identified themes were then analysed to determine common safety culture dimensions and elements reported across the literature. This thematic synthesis provided the foundation for the subsequent prioritisation and framework development phases of the study.

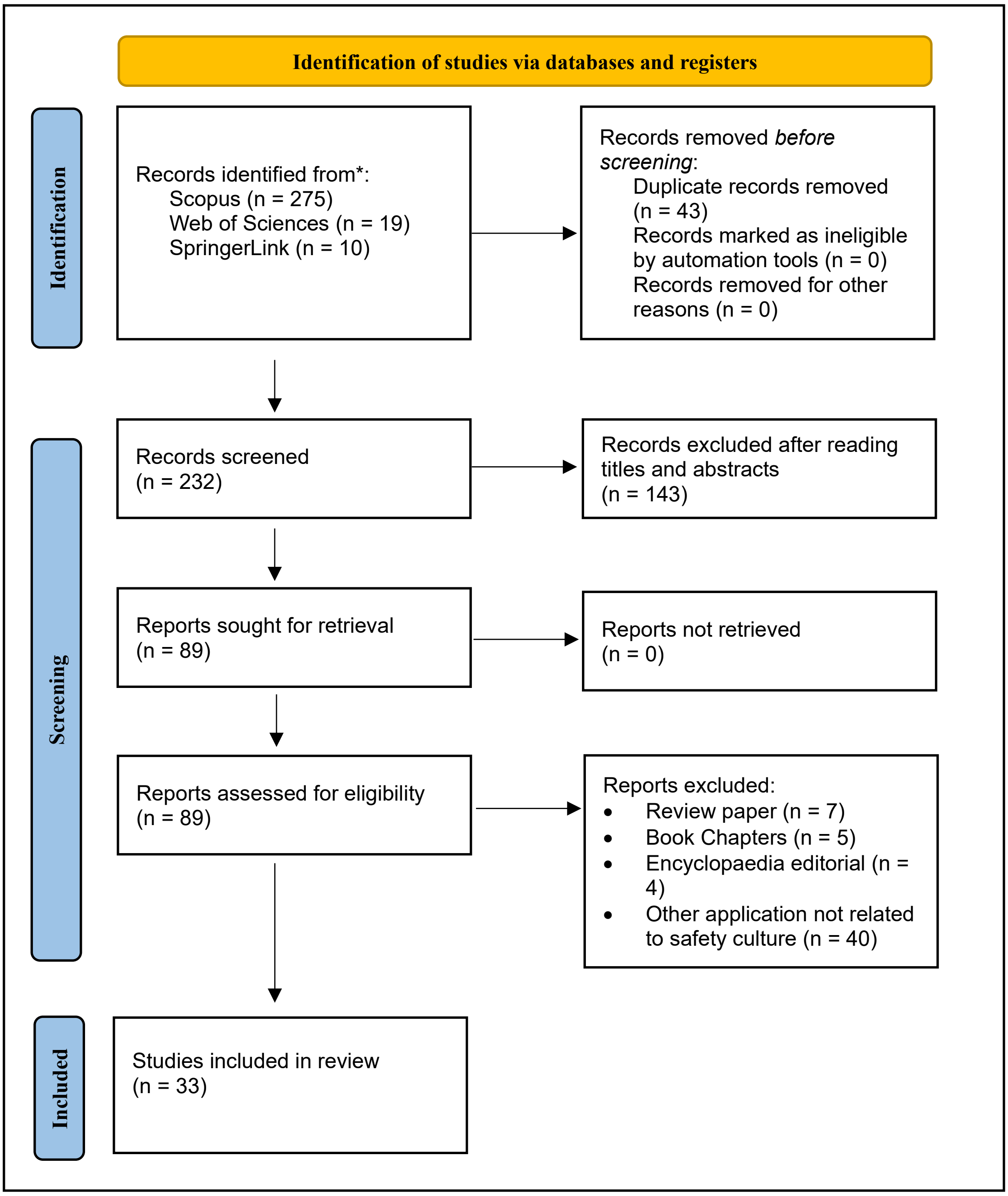

Figure 3.1 PRISMA Flow Diagram. Summarises the process of study identification, screening, eligibility, and inclusion for Thematic Studies on Safety Culture in the Oil and Gas Industry.

3.3.2 Phase 2: Development and Validation of a Questionnaire on Safety Culture Elements Preference for Oil and Gas

a) Study Population

The study engaged a specific cohort of 40 participants, comprising safety and health practitioners, policymakers, academicians, and industry employees in the Malaysian oil and gas sector. To ensure a robust content validation process, an expert panel was carefully selected from this cohort based on their roles, experience, and expertise in safety culture. The panel included senior safety and health officers with at least 5 years of experience in the oil and gas industry, policymakers involved in the formulation and implementation of safety regulations, academicians with research expertise in occupational safety and health, and experienced field-level employees with direct involvement in safety practices. This diverse composition ensured a comprehensive understanding of safety culture elements from strategic, academic, and practical perspectives. The sample size of 40 participants was chosen based on established guidelines for content validation studies, which recommend expert panels ranging from 5 to 40 participants to ensure sufficient reliability and diverse insights (Creswell, 2017). Given the targeted nature of the study, focusing on domain experts rather than a general population, a sample size of 40 was deemed appropriate to balance expert diversity and feasibility while achieving meaningful validation results. This approach aligns with previous research in safety culture assessment, which emphasizes quality over quantity in expert-driven validation processes.

The selection of panel members was guided by their qualifications, such as professional certifications (e.g., NIOSH, DOSH), academic credentials (e.g., Ph.D. or Master’s degrees in relevant fields) and their demonstrated contributions to safety culture through publications, policy development, or operational improvements. The inclusion of these experts was instrumental in validating the questionnaire’s content, ensuring its relevance and applicability to the oil and gas sector. To facilitate broad and inclusive data collection, the questionnaire was distributed online and completed via self-administration. This approach ensured voluntary participation and adhered to ethical considerations, including informed consent. The online distribution method also overcame geographical limitations, enhancing the representativeness of the data across diverse operational and cultural contexts in the industry (De Filippi, 2022 and Lenaerts et al., 2021). Data collection was conducted in March 2024.

b) Questionnaire

To develop the questionnaire, an extensive literature review was conducted to identify relevant questionnaire items. Sources included major databases such as Web of Science, Scopus and SpringerLink (Martin et al., 2018, Mongeon, 2016 and Bramer et al., 2017). The questionnaire was structured according to Saaty's Analytic Hierarchy Process (AHP) methodology (Saaty, 2008), ensuring alignment with established analytical standards. The questionnaire consisted of 52 questions, divided into four constructs: psychological, situational, behavioural and preference of element containing 6, 15, 28 and 3 questions respectively. In each section, participants were presented with pairs of variables representing different aspects of the three criteria and were asked to indicate their preferences. Each variable was clearly defined to maintain clarity and consistency in the responses. The number of questionnaire items allocated to each section was determined based on the number of safety culture dimensions and sub-elements identified through the literature review. The behavioural dimension contained a larger number of items because it comprised eight validated sub-elements, namely management commitment, safety commitment, safety ownership, safety training, safety communication, reward recognition, safety investment, and safety competency. In contrast, the preference section was designed solely to rank and compare the relative importance of the three main safety culture dimensions (psychological, behavioural, and situational) and therefore required fewer items. Preferences were quantified using a Likert scale from 0 to 9, where 1 indicated equal importance, and 9 indicated absolute importance, with intermediate values reflecting varying degrees of preference. All questions were closed-ended to streamline the analysis process.

c) Face Validity

Face validity was conducted in a face-to-face format to enhance direct feedback and interaction. Each of the five respondents, who met the inclusion criteria for the target population of the formal study, was invited individually to review the questionnaire items and complete the face validity feedback form. This approach ensured that feedback was detailed and specific, allowing for immediate clarification and discussion of any ambiguities. This method emphasized measuring whether the items were expressed clearly and effectively, reducing confusion from excessive professionalism or ambiguity. The selection of five respondents for face validity aligns with standard recommendations in psychometric research, where small expert panels (typically between 5 and 10 participants) are considered sufficient for qualitative evaluations of item clarity and relevance (Polit, 2006). Since face validity is a subjective assessment rather than a statistical validation, the primary objective was to gather focused, high-quality feedback from experienced professionals rather than achieving a large sample size (Frantz, 2019 and Polit et al., 2007). The five respondents were selected based on their expertise in safety culture and occupational health, ensuring that their input was meaningful and representative of the target industry.

To assess the face validity of the questionnaire designed for prioritising safety culture in the oil and gas industry, a panel of experts was assembled. This panel included academicians, industry practitioners, and policymakers, all with extensive knowledge of the psychological, situational, and behavioural aspects of safety culture. Each expert was provided with the questionnaire, and the Analytic Hierarchy Process (AHP) methodology employed in its design was explained to ensure they understood the rationale behind the scaling and pairing of variables. The experts were tasked with evaluating the relevance and clarity of each questionnaire item in relation to the defined constructs of psychological, situational, and behavioural criteria. They reviewed the definitions provided for each variable to determine their clarity and assessed whether the questionnaire items collectively captured the nuances of safety culture effectively. Special attention was given to the Likert scale, which ranged from 0 to 9, to evaluate whether it effectively captured the gradations in preference and importance as intended by the study's design. Based on the feedback received from the five respondents, no modifications were deemed necessary, as all participants confirmed that the questionnaire items were clear, relevant, and comprehensible. The consistency in expert responses indicated that the questionnaire was well-structured and effectively captured the intended safety culture dimensions, supporting its readiness for further validation.

d) Content Validity Index (CVI)

An expert panel comprising seven specialists was convened to establish the content validity of the research instrument intended for a pilot study. The panel included three safety and health practitioners from the oil and gas industry, one enforcement officer from the Department of Occupational Safety and Health, one officer from the National Institute of Occupational Safety and Health, and two academicians from

Universiti Teknologi MARA (UiTM) and Universiti Putra Malaysia (UPM). These experts were selected based on their extensive knowledge and direct experience relevant to the research topic. The evaluation process was meticulously structured to ensure a comprehensive review and high relevance of the questionnaire items to the domain being measured. Each questionnaire item was subjected to rigorous scrutiny to assess its clarity, relevance, and unambiguous presentation. The structured approach used a four-point Likert scale for the content assessment, as recommended by Polit and Beck (2006) (Pilot, 2006) presented in Table 3.2.

Table 3.2
Four-points Likert Scale for Content Validity Index (CVI)

Rating	Definition	Description
1	Not relevant	The item does not pertain to the domain being measured.
2	Somewhat relevant	The item shows some relevance but is inadequate in content.
3	Quite relevant	The item is appropriate and offers significant relevance to the domain.
4	Highly relevant	The item is extremely pertinent and provides comprehensive coverage of the domain.

This four-point scale was chosen to prevent a neutral midpoint, thereby encouraging clear distinctions in the ratings provided by the experts. For the Content Validity Index (CVI) calculations, items rated as '3' or '4' were considered relevant, while items rated as '1' or '2' were deemed not relevant, indicating potential areas for revision or removal. The threshold for the Item-Level Content Validity Index (I-CVI) was set at ≥ 0.78, following the recommendations of Polit and Beck (2006). This threshold is widely recognised in the literature as an indicator of strong content validity and ensures that the instrument is sufficiently rigorous for further testing. The ratings assigned by the panel were aggregated to calculate both the I-CVI for individual items and the Scale-Level Content Validity Index (S-CVI) for the entire instrument**.** During the review process, experts were also encouraged to provide qualitative feedback on each item, suggesting possible modifications or expressing concerns regarding the wording and the item's alignment with the research objectives**.** This collaborative and iterative process was designed to enhance the precision and applicability of the research instrument, thereby ensuring its validity and effectiveness in capturing the necessary data for the study.

During the content validation process, any items that scored below the threshold of ≥0.78 on the Item-Level Content Validity Index (I-CVI) were carefully reviewed and addressed based on feedback from the expert panel (Polit, 2006 and Frantz, 2019). Low-scoring items were either revised for clarity, relevance, or alignment with the research objectives or in cases where the item was deemed irrelevant or redundant, removed entirely from the questionnaire (Polit, 2007 and Lynn, 1986). This process ensured that the final set of items was highly relevant, clear, and representative of the safety culture dimensions being measured. While the Content Validity Index (CVI) analysis primarily focused on the Item-Level Content Validity Index (I-CVI) to evaluate the relevance and clarity of individual items, the Scale-Level Content Validity Index (S-CVI) was not calculated in this study. The decision to omit S-CVI, including S-CVI/Average and S-CVI/Universal Agreement, was based on the relatively small size of the expert panel as the S-CVI/Universal Agreement method could lead to overly stringent thresholds that might underestimate the overall validity of the instrument (Saaty, 2008 and Zamanzadeh et al., 2015). Moreover, the primary aim of the validation process was to refine individual questionnaire items rather than assess the overall scale-level validity, which aligns with the specific research objectives. Future studies with larger expert panels may incorporate S-CVI measures to complement the I-CVI findings and provide additional insights into scale-level content validity.

e) Content Validation Ratio (CVR)

This section outlines the use of the Content Validity Ratio (CVR), a measure originally proposed by Lawshe in 1975 (Rubio et al., 2003), for assessing the essentiality of questionnaire items in the context of safety culture in the oil and gas industry. The CVR offers a quantitative assessment scale ranging from -1 to +1, reflecting a spectrum of expert opinions on the necessity of survey items. Expert Panel was formed based on selected group of subject matter experts is convened, bringing diverse insights from various facets of safety culture. Their expertise is critical in defining what constitutes 'essential' content within the survey. Each item of the questionnaire is rated by these experts using a four-point Likert scale, defined in Table 3.3

Table 3.3
Four-Points Likert Scale for Content Validity Ratio (CVR)

Rating	Definition	Description
1	Not necessary	The item does not contribute essential information to the domain.
2	Useful but not essential	The item provides useful information but is not critical.
3	Essential	The item is fundamental and should be included in the survey.
4	Very essential	The item is crucial for comprehensive coverage of the survey domain.

The CVR for each item is calculated using the formula:

$$CVR = \frac{(n_e - N/2)}{N/2} \tag{3.1}$$

Here, n_e is the number of experts who rated the item as 'essential' or 'very essential' (ratings 3 and 4), and *N* is the total number of experts. Items receiving a CVR close to +1 are considered highly essential, indicating strong expert consensus. Conversely, items with a CVR near or below zero may be reconsidered or revised based on expert feedback.

Following the content validation process, the Content Validity Ratio (CVR) was employed to evaluate the relevance and essentiality of the questionnaire items from the perspective of subject matter experts. CVR is widely used during instrument development to ensure that the measurement items adequately represent the constructs being investigated. Once the content validity of the instrument was established, Exploratory Factor Analysis (EFA) was conducted to examine the underlying factor structure of the questionnaire and determine whether the items were grouped according to their intended constructs. The use of EFA is appropriate in exploratory studies where constructs are identified from literature and expert input prior to further validation.

f) Reliability Analysis

The application of Cronbach's alpha to evaluate the reliability of the newly developed Safety Culture Preference Survey was utilised. Cronbach's alpha provides a measure from 0 to 1, reflecting the degree of interrelatedness among the items on the survey. The calculation takes into account the number of items in the test, the average correlation among the items, and the dimensionality of the underlying construct. Commonly, alpha values between 0.70 and 0.90 are considered acceptable in psychometric testing, indicating sufficient internal consistency without excessive redundancy. Alpha values below 0.70 may suggest that the test items do not adequately capture the same construct or are poorly correlated. Alpha values exceeding 0.90 may indicate redundancy among items, suggesting that some items may be duplicative and could potentially be removed to streamline the survey. The alpha values for each dimension of the safety culture survey are critically analysed to ensure that each set of items consistently measures a single construct. Based on the alpha results, adjustments may be made to the survey to either refine or remove items to enhance the survey's overall reliability.

While Exploratory Factor Analysis (EFA) or Confirmatory Factor Analysis (CFA) is typically expected for construct validation of newly developed questionnaires, these analyses were not performed in this study due to the primary focus on content validation and reliability assessment (Netemeyer, 2003). Given the relatively small sample size and the study's objective to first establish an initial validation framework for the SCQ, conducting factor analysis would have been limited in its generalizability. Future studies with larger and more diverse samples should employ EFA to explore the underlying factor structure of the SCQ and CFA to confirm its construct validity across different industry settings. These additional analyses will further strengthen the psychometric robustness of the SCQ, ensuring its applicability across broader populations (Raykov, 2011).

g) Statistical Analysis

The structured approach to the statistical analysis of the pilot study was conducted to verify the validity and reliability of the Safety Culture Preference Questionnaire (SCPQ). Data for the pilot study was collected via an online survey administered using Google Forms, ensuring efficient and broad accessibility. Responses were automatically recorded and stored securely online, facilitating a streamlined data collection process. The complete dataset was exported from Google Forms and directly imported into SPSS version 29.0 for comprehensive analysis. Prior to analysis, data was checked for completeness and consistency to ensure the accuracy of the results. The analysis was strictly confined to content validity and reliability assessments, aligning with the research objectives to refine the survey's design based on empirical evidence. Statistical analysis methods to assess the extent to which the survey items are an adequate reflection of the construct to measure the domain of safety culture. Cronbach's alpha was calculated to evaluate the internal consistency of the survey, ensuring that the items reliably measure the same concept. Descriptive statistics were not performed as the primary focus was to validate the instrument's content and structure rather than to explore the data distribution or demographic characteristics of the sample.

3.3.3 Phase 3: Data Coding and Interpretation Stakeholder Priorities of Safety Culture Preferences in the Oil and Gas

a) Study Design, Framework and Participants

A cross-sectional study design was conducted for oil and gas sector. Data collection was performed gradually from April to May 2024 until the required sample size was obtained. The respondents were approached physically or virtually. In addition, informed consent was obtained from all subjects. The objective of this study was explained to each of the respondent prior data collection. This research employed a structured safety culture framework to analyse three essential aspects of safety culture in the oil and gas industry, namely psychological, behavioural, and situational factors (Figure 3.2). A total of 18 sub-elements within these categories were assessed to evaluate their impact on overall safety practices. Table 3.4 summarised 18 sub-elements with reference to sources. Psychological elements include personal attitudes towards safety, understanding of safety practices, perceptions of risks, and the influence of peers on safety compliance. Behavioural elements are assessed through visible actions and encompass eight sub-components such as management's safety commitment, employee safety commitment, safety ownership, safety communication, safety investment, safety training, and the recognition of safety-oriented behaviours. Next, situational factors address external conditions impacting safety, including clear safety rules, incident reporting systems, the working environment, employee satisfaction, and the quality of technology and equipment used. This comprehensive analysis can guide the identification of the most influential factors affecting safety culture and the design of targeted improvements in the oil and gas sector.

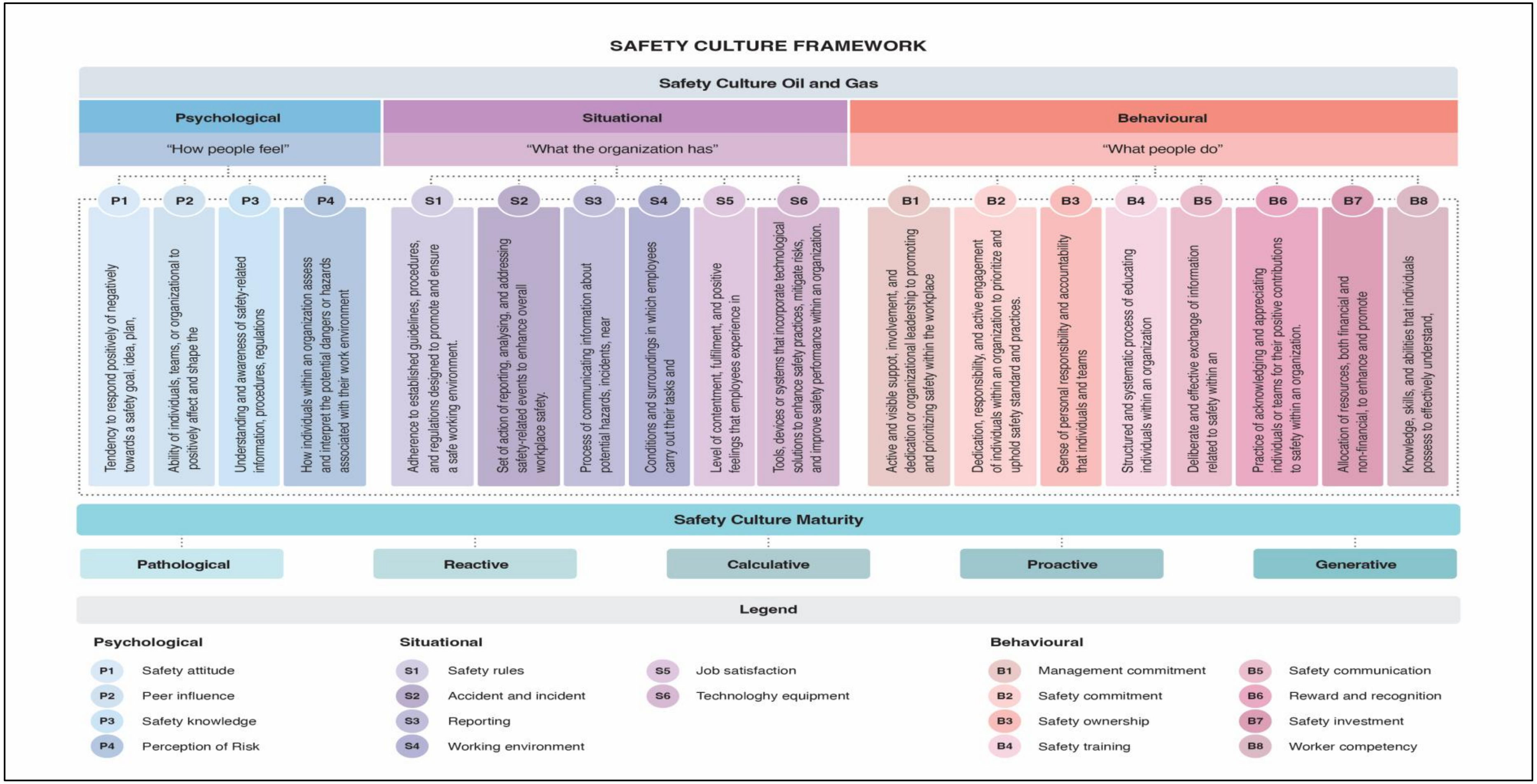

Figure 3.2 Safety Culture Elements of the Oil and Gas Industry

Table 3.4
Safety Culture Elements Reference of Sources

Elements	Sub-elements	Reference
Psychological	Safety attitude	(Rasmussen, et al., 2022 and Al-Mekhlafi et al., 2021)
	Peer influence	(Rasmussen, et al., 2022)
	Safety knowledge	(Kalter et al., 2022)
	Perception of risk	(Phusavat et al., 2015)
Situational	Safety rules	(Iqbal et al., 2019)
	Accident and incident	(Almazrouei et al., 2020 and Glebova et al., 2023)
	Reporting	(Chen et al., 2013)
	Working environment	(Sugiono et al., 2020)
	Job satisfaction	(Elbrahimi et al., 2016)
	Technology equipment	(Fabiano et al., 2022)
Behavioural	Management commitment	(Almazrouei et al., 2019)
	Safety commitment	(Sughiono et al., 2020 and Almazrouei et al., 2019)
	Safety ownership	(Ebrahimi et al., 2016)
	Safety training	(Ebrahimi et al., 2016 and Almazrouei et al., 2019)
	Safety communication	(Mohamad et al., 2022 and Laplonge, 2014)
	Reward recognition	(Chen et al., 2013)
	Safety investment	(Quoquab et al., 2018)
	Worker competency	(Iqbal et al., 2019 and Kalteh et al., 2022)

As for study participants, a diverse group of participants spanning a broad age range with varied educational qualifications, ranging from PhDs to professional certificates, was recruited from various organisational types, with nearly equal distribution between government or statutory bodies and private or multinational companies. These participants were drawn among those actively involved in occupational safety and health (OSH) from multiple sectors related to the oil and gas industry, including those from governmental and regulatory bodies and those with educational roles specific to OSH. Professionally, their roles spanned from safety and health practitioners, government regulators, lecturers, researchers, and trainers, to managers. This demographic makeup of participants who were directly engaged with safety practices in their respective fields ensured a comprehensive insight from various professional perspectives and areas of expertise that would generate a thorough understanding of safety practices and culture across the industry.

b) Identification of Stakeholders

The sampling method of stakeholders was performed via purposeful and snowball sampling techniques (Karamidehkordi, et al., 2024). Under purposeful sampling, participants with direct involvement or influence in safety culture within the Malaysian oil and gas sector were recruited to ensure representation from key stakeholders. Additionally, snowball sampling was utilised whereby additional participants were referred by those already included in the study via their industry contacts. This approach led to the inclusion of individuals with diverse perspectives and experiences, thus enhancing the comprehensiveness of the stakeholder sample in this study. The required sample size was determined based on the guidelines for qualitative research in similar studies, which suggest that a sample size of 30–50 participants is sufficient to reach saturation, where no new information is being discovered (Darko et al., 2019, Lim et al., 2024 and Chompook et al., 2023). A total of 40 subject matter experts (SMEs) participated in this study.

The eligibility criteria were properly designed to ensure a comprehensive and representative sample of study participants. Firstly, only individuals with direct involvement or responsibility in safety management or decision-making within the industry were included to guarantee first-hand insights of safety culture practices. Secondly, they were recruited from diverse sectors within the industry, including government/statutory bodies and private or multinational companies, to capture a broad spectrum of perspectives. Additionally, they could be holding varied professional roles, such as Safety & Health Practitioners, Government/Regulator Officers, academic professionals, and managerial positions to ensure a multidimensional understanding of safety culture dynamics. Lastly, active engagement in OSH activities is a key criterion as participants must demonstrate a tangible commitment to safety issues through their professional involvement or responsibilities. These selection criteria enabled comprehensive insights from stakeholders with the relevant expertise and experiences to enrich the depth and breadth of the study's findings.

For the study recruitment, potential participants were contacted through industry associations, professional networks, and relevant organisations. Existing connections were leveraged to identify suitable individuals with direct involvement in safety culture within the sector. Personalised invitations were then sent out, detailing the purpose and significance of the research. Various channels including online platforms, email, and phone calls were utilised to facilitate communication. To provide a clear overview of the participants, the profile of the experts has been summarised in Table 3.5. This table includes key details such as the professional roles of the experts, their years of experience, the sectors they represent, and their specific involvement in safety management within the oil and gas industry.

Table 3.5
Experts Profile

Expert ID	Professional Role	Experience (Year)	Safety Involvement
1	Safety & health practitioner	5*	Direct responsibility managing safety and health
2	Government/ Regulator	5*	Policy formulation, oversight
3	Academic Professional (Lecturer/Researcher/Trainer	5*	Research, teaching and training in safety and health
4	Managerial	5*	Strategic planning, decision maker

Note: *: 5 years and above

c) Survey and Questionnaire Design

A structured questionnaire was designed based on the AHP methodology (Saaty, 2008). The questionnaire comprised 49 questions organised into three sections, i.e. psychological, situational, and behavioural, with each section containing 6, 15 and 28 questions, respectively. Within each section, experts were asked to indicate their preferences between pairs of variables representing different combinations of the three criteria. Definitions of each variable were provided to ensure clarity and consistency in responses. To quantify preferences, a Likert scale ranging from 1 to 9 was utilised, where 1 denoted equal importance and 9 denoted absolute importance, with intermediate values representing varying degrees of preference. The questionnaire was administered using Google Forms an accessible and user-friendly platform for data collection. Through this structured approach, stakeholder preferences on safety culture criteria were systematically elicited and analysed. The AHP methodology was utilised to prioritise these criteria effectively.

d) Multicriteria Decision-making Methodology Selection

The chosen methodology of AHP represents a robust framework for capturing stakeholder preferences in the context of safety culture within the Malaysian oil and gas industry. Developed by Thomas Saaty, AHP provides a structured approach to convert qualitative evaluations into numerical values for each element in the hierarchy, thus enabling precise comparisons of diverse and potentially incommensurable factors across the entire range of safety culture criteria in a rational and consistent manner. The methodology involves several systematic steps, from criteria identification, pairwise comparison, and consistency check, to priority calculation. In this study, psychological, behavioural, and situational factors were identified as criteria and weighted through pairwise comparisons by SMEs. The consistency of judgments was rigorously verified using the consistency ratio, ensuring the reliability of the results. Ultimately, priority scores were calculated for each safety culture influencing factor as a valuable guide for decision-making and resource allocation within the industry.

e) Data Analysis Plan

Initially, the survey responses comprising ratings or rankings of various safety and health criteria as assessed across distinct professional roles were collected and compiled. Data cleaning was performed. Missing data management was conducted to maintain consistency across responses before data analysis AHP. The responses were organised into a matrix format to allow a direct comparison of each criterion across different roles, hence facilitating an efficient evaluation process in the subsequent stages of the AHP analysis.

The preparation of the pairwise comparison matrix involved comparing each criterion against every other criterion within the context of the specific professional roles. Each matrix element a_{ij} represents the relative importance of criterion i compared to criterion j, as perceived by the respondents. This critical phase involved constructing pairwise comparison matrices for each criterion against each professional role. These matrices served to capture and quantifiy the respondents' assessments regarding the relative importance of one factor compared to another within the context of their professional roles. To calculate the priority vector, the average of the normalized values was used. Specifically, each matrix was normalized by dividing each element by the sum of its respective column. The average of these normalized values across each row was then calculated to determine the priority vector. For each of these matrices, the priority vector was calculated by normalising the sum of each column in the matrix and then averaging the normalised values across each row. This process can be mathematically represented as follows:

$$a'_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \tag{3.2}$$

Where a_{ij} is the element of the matrix at the i^{th} row and j^{th} column, and n is the number of elements in the column. The calculation of the priority vector is represented as follows:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} a'_{ij} \tag{3.3}$$

Where w_i is the weight for the i^{th} criterion, and a'_{ij} is the normalised value from the first step. This step transformed qualitative judgments provided by the survey responses into quantifiable weights. It was an essential step to facilitate a more objective analysis. To enhance the reliability and accuracy of these calculated priorities, the eigenvalue method was then employed. This method was particularly effective in addressing and adjusting for potential inconsistencies in human judgment that often arise during the survey process:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \tag{3.4}$$

Where λ_{max} is the largest eigenvalue of the matrix A, Aw is the matrix-vector product of A and w, and w_i is the i^{th} component of the priority vector w. By utilising the eigenvalue method, the AHP model ensured that the derived weights would not only be a mathematical reflection of the survey responses but would also be robust against subjective biases, thereby strengthening the overall decision-making framework within the study. Following the determination of priority vectors in the AHP model, the next crucial step was to calculate the Consistency Index (CI) for each comparison matrix.

The CI was instrumental in assessing the reliability of the judgments made during the pairwise comparisons. CI was used to evaluate whether the preferences and priorities derived from the survey responses were logically coherent. The calculation of the CI was performed using the formula:

$$CI = \frac{\lambda_{\max^2} - n}{n - 1} \tag{3.5}$$

Where λ_{max} represents the largest eigenvalue of the matrix, and n is the number of criteria or elements within the matrix. This formula measures the deviation of λ_{max} from n, normalised by $n-1$ to scale the index appropriately for matrices of different sizes. A standard threshold for the CI is 0.1. A CI value exceeding this threshold indicates potential inconsistencies within the judgments, suggesting a need to revisit and possibly revise the pairwise comparisons to reduce bias or inconsistency. To further validate the consistency of the matrix, the Consistency Ratio (CR) is computed by comparing the CI to the Random Index (RI), which is a predefined value based on the matrix size. The CR is given by:

$$CR = \frac{CI}{RI} \tag{3.6}$$

A CR value less than or equal to 0.1 is generally acceptable, indicating a reasonable level of consistency in the judgments. If the CR exceeds 0.1, it is advisable to re-evaluate the pairwise comparisons to enhance the decision-making process's accuracy and reliability. In this study, this step was fundamental to ensure the robustness of the AHP analysis as it would be used to confirm that the derived priorities were based on coherent and reliable judgments. To further ensure the robustness of the final rankings, a sensitivity analysis was applied. This analysis involved systematically varying the input parameters to assess how changes in these parameters affected the final rankings. The sensitivity analysis provided additional confidence in the stability of the results, ensuring that the rankings derived from the AHP model remained consistent under different scenarios. This step was critical in validating the robustness and reliability of the conclusions drawn from the study.

3.3.4 Phase 4: Modelling the Architecture of Safety Culture: Psychometric Validation and Predictors of Safety Outcomes in Malaysian Industries

a) Study Design and Setting

This cross-sectional analytical study builds upon the structured methodological approach established in our earlier work on safety culture within the Malaysian oil and gas industry, which employed a systematic framework to evaluate psychological, behavioural, and situational safety dimensions (Rahim et al., 2024). In the present study, we extended this design to examine the structural relationships among these higher-order constructs and to identify demographic and organisational predictors influencing safety outcomes. Data were collected from workers across multiple occupational sectors including oil and gas, manufacturing, and service-related industries in Malaysia to ensure diverse representation of safety practices and organisational environments. Consistent with the principles applied in our previous study, the cross-sectional design allowed simultaneous assessment of latent constructs and observable predictors, enabling a comprehensive examination of individual- and system-level mechanisms that shape safety performance. This approach provided a robust platform for validating the multidimensional structure of safety culture and for identifying meaningful pathways through which education, occupational role, sector, and OSH involvement contribute to overall safety outcomes.

b) Participants and Sampling Strategy

A purposive sampling approach was employed to recruit employees with direct exposure to workplace safety practices and OSH-related procedures. Inclusion criteria required participants to be ≥18 years old and employed in organisations with established safety management structures. Respondents represented diverse educational backgrounds (professional certificate, bachelor's degree, master's degree, and PhD), occupational roles (general employees, managers, and Safety & Health Practitioners), and levels of OSH involvement. Participation was voluntary, and all respondents provided informed consent prior to survey completion.

c) Instrumentation and Measures

Safety culture in this study was measured using a structured instrument adapted from our previously validated Safety Culture Questionnaire (SCQ), which demonstrated strong content validity (CVI = 0.86–1.00) and excellent reliability across psychological, behavioural, and situational constructs (Rahim et al., 2025). Consistent with this validated framework, safety culture was operationalised as a higher-order construct comprising three dimensions: Psychological Safety (safety attitude, safety influence, safety knowledge), Behavioural Safety (management commitment, safety ownership, safety training, communication, reward recognition, safety investment, safety competency, safety commitment), and Situational Safety (safety rule compliance, safety reporting, work environment, job satisfaction, technology and equipment, accident/incident experience). All indicators were assessed using structured Likert-type scales and selected based on their theoretical relevance and prior psychometric support. Predictor variables included demographic factors (gender, age) and organisational characteristics (educational background, occupational role, sector, OSH involvement), which were incorporated into the regression and SEM analyses to examine their independent contribution to safety outcomes.

d) Statistical Analysis

Statistical analyses were conducted in two stages to evaluate both the predictors of safety outcomes and the psychometric strength of the safety culture constructs. First, random-effects regression modelling was performed to quantify the influence of demographic and organisational variables, yielding robust estimates that accounted for potential clustering across sectors and occupational groups. Standardised coefficients (β), standard errors, t-values, and p-values were computed to identify significant predictors. Second, the measurement model was assessed using confirmatory factor analysis (CFA) to validate the psychological, behavioural, and situational dimensions of safety culture. Model evaluation focused on standardised factor loadings, composite reliability (CR $\geq$ 0.70), average variance extracted (AVE $\geq$ 0.50), and indicator relevance (loading $\geq$ 0.30). Items that did not meet statistical significance were retained only when theoretically essential but excluded from structural interpretation. This integrated analytical approach ensured rigorous assessment of construct validity and provided a robust foundation for subsequent structural modelling.

e) Structural Equation Modelling (SEM)

Structural Equation Modelling (SEM) was employed to rigorously examine the directional and hierarchical relationships among the three higher-order safety constructs Psychological Safety, Behavioural Safety, and Situational Safety and their associated indicators. SEM was selected as the analytical framework because it enables simultaneous testing of both measurement and structural components, offering a comprehensive assessment of how individual perceptions, behavioural practices, and environmental conditions collectively shape overall safety outcomes. Model estimation was performed using the maximum likelihood method, which provides stable and efficient parameter estimates when analysing complex multivariate relationships. The structural model incorporated all validated indicators from the measurement model, allowing standardised path coefficients to be generated for each latent construct. These coefficients were interpreted to determine the magnitude and significance of each construct's contribution to the overarching safety culture framework. By modelling higher-order constructs, SEM captured the multidimensional nature of safety culture more effectively than traditional regression techniques, revealing how cognitive attitudes, operational behaviours, and situational conditions interact within a unified safety ecosystem. Importantly, SEM facilitated evaluation of model fit, construct loadings, and inter-construct pathways in a single analytical procedure, enhancing the internal coherence and empirical robustness of the study. This integrated approach enabled identification of the most influential safety mechanisms, validated the hierarchical structure of safety culture, and provided a nuanced understanding of the pathways through which demographic and organisational factors influence safety performance. All SEM analyses were conducted using established multivariate statistical software, adhering to recognised standards for latent variable modelling and ensuring methodological rigour suitable for high-impact scientific publication.

Structural Equation Modelling (SEM) was employed to validate the relationships among the psychological, behavioural, and situational dimensions of safety culture identified through the literature review and expert prioritisation process. SEM was selected because it enables the simultaneous examination of multiple relationships between latent constructs and observed variables while accounting for measurement error. Compared with traditional multivariate techniques such as multiple regression, SEM provides a more comprehensive assessment of construct validity, model fit, and causal relationships among variables. The application of SEM in safety culture research has been widely reported in previous studies due to its ability to validate theoretical frameworks and assess the relative contribution of individual constructs to the overall model. In this study, SEM was utilised to determine the strength and significance of the relationships among safety culture dimensions and to provide empirical support for the proposed safety culture framework.

3.3.5 Phase 5: Design and Development of the BOSCA Mobile Application Interface: A Behaviourally Informed Digital Framework for Safety Culture Transformation

a) Study Design and Interface Development Framework

The interface of the Behavioural Occupational Safety Culture Application (BOSCA) was developed through a structured, six-step framework (Figure 3.3) that integrated behavioural theory, user-centred design, and iterative validation. This process built upon previously established behavioural determinants of safety culture in the Malaysian oil and gas industry (Section 3.3.3). The current study specifically translated those determinants into the digital design and interface development of the BOSCA mobile application.

Step 1: Needs Assessment: The needs-assessment component was based on a previously published analysis that applied the Analytic Hierarchy Process (AHP) to decode stakeholder priorities for safety-culture improvement in the oil and gas sector (Section 3.3.3). That study identified leadership commitment, safety ownership, and communication as the top-ranked behavioural drivers of safety performance. These validated findings served as the theoretical foundation for the BOSCA interface design. In the present phase, structured consultations were conducted with 15 industry practitioners including safety managers, officers, and engineers to contextualise those findings for digital application. The priorities identified in the earlier study were operationalised into interface objectives such as enhanced dashboard visibility, streamlined navigation flow, and dynamic communication alerts.

Step 1: Needs Assessment
• Identify safety culture gaps using Analytic Hierarchy Process (AHP)
• Assess behavioural and management-related safety issues
• Define goals to strengthen safety leadership and engagement

Step 2: Module Matrices
• Define key safety modules: Management Commitment, Safety Ownership, Safety Training, Safety Communication, Reward Recognition, Safety Investment

Step 3: Theoretical and Practical Applications
• Apply safety culture frameworks and behaviour-based safety (BBS) principles
• Align modules with theories of safety motivation and continuous improvement mapping between modules and expected outcomes

Step 4: Program Design
• Design interactive mobile app interfaces for each module
• Integrate dashboards, feedback, reporting and learning tools
• Create training materials, forms, and digital workflows

Step 5: Adoption and Implementation Plan
• Pilots test the mobile app among target user groups (managers, employees, auditors)
• Gather user feedback and refine features
• Develop implementation timeline and resource allocation

Step 6: Evaluation Plan
• Conduct usability testing and behaviour-change evaluation
• Monitor KPI (incident rate reduction; training completion; user engagement)
• Refine modules based on continuous feedback

Figure 3.3 Six-Step Framework Illustrating the Mobile Application Development and Implementation Process. Enhancing Safety Culture in the Oil and Gas Industry by Integrating Assessment, Design, Implementation and Evaluation Phases.

Step 2: Module Matrices: Findings from Step 1 were used to construct the module matrices that defined seven thematic domains: *Management Commitment*, *Safety Commitment*, *Safety Ownership*, *Safety Training and Sanction*, *Safety Communication*, *Reward and Recognition*, and *Safety Investment*. Each domain was linked to specific behavioural goals and performance indicators, forming the foundation for BOSCA's core digital modules.

Step 3: Theoretical and Design Application: The interface design followed the Information–Motivation–Behavioural Skills (IMB) model and behavioural-based safety (BBS) principles. Motivation was expressed through gamified visuals and progress indicators; behavioural skills through interactive learning and reporting tools; and moderating factors through real-time feedback and communication channels. Material Design 3 guidelines were used to standardise layout consistency, accessibility, and aesthetic clarity. Colour codes reflected safety priorities (e.g., red = hazard alert, green = achievement, blue = training) to reinforce intuitive decision-making.

Step 4: Interface Prototyping and Program Design: Wireframes were produced using Figma (version 116.2.12) and iteratively refined through co-design sessions with representative end-users. Each prototype incorporated BOSCA's six core modules; Audit, Training, Reward Recognition, Incident Reporting, Competency, and Communication Alerts arranged within an adaptive dashboard layout. The final interface was developed using Flutter (Dart framework) for cross-platform functionality (Android and iOS) and linked to a Firebase Cloud Firestore backend for real-time data synchronisation. Visual assets were exported as vector-based components to optimise responsiveness and minimise load time.

Step 5: Adoption and Implementation Plan: A prototype of the BOSCA interface was pilot tested with ten participants drawn from the same professional population used in the prior study. Testing sessions evaluated ease of navigation, visibility under field conditions, and responsiveness of interactive features. Structured questionnaires and observation checklists were used to collect feedback, leading to refinements in button sizing, notification timing, and colour contrast.

3.3.6 Phase 6: Developing a Real-Time Behavioural Safety Culture Framework (BOSCA Using Progressive Web Applications (PWA))

The development process of the BOSCA is illustrated in Figure 3.4. This process comprises four main phases: requirements, design, implementation, and testing. In the requirements phase, the key elements of BOSCA were reviewed and analysed through expert interviews and an exploration of existing systems to define and refine the application's requirements. The expert interview and prioritisation process that informed the selection of behavioural elements for the BOSCA framework were previously conducted and published in a peer-reviewed article (Rahim et al., 2024). In that study, 40 subject matter experts (SMEs) from four key stakeholder groups; safety practitioners, regulators, academicians and industry managers were selected using purposive and snowball sampling techniques. Eligibility was based on active engagement in occupational safety and health (OSH) with at least five years of experience. The analytic hierarchy process (AHP) was applied to evaluate 18 safety culture sub-elements across psychological, behavioural and situational dimensions. The findings identified behavioural elements as the most influential, which directly informed the content and structure of the BOSCA application developed in this study.

In the design phase, the system architecture and user interfaces were meticulously designed to create a cohesive structure. Subsequently, the implementation phase involved developing the web/mobile application using *Vue.js* for the frontend, building a robust database using *Supabase,* and deploying the model on Netlify to ensure seamless integration and accessibility. Finally, the testing phase encompassed rigorous system and usability testing to validate the effectiveness and user-friendliness of BOSCA. The following subsections elaborate on each phase of the development process, providing further details on the methodologies and technologies employed. This phase focuses exclusively on the conceptualisation, system design, and development process of the BOSCA-PWA framework. A separate study is being undertaken to validate the usability and effectiveness of the application in real-world settings, which will be reported in a subsequent publication.

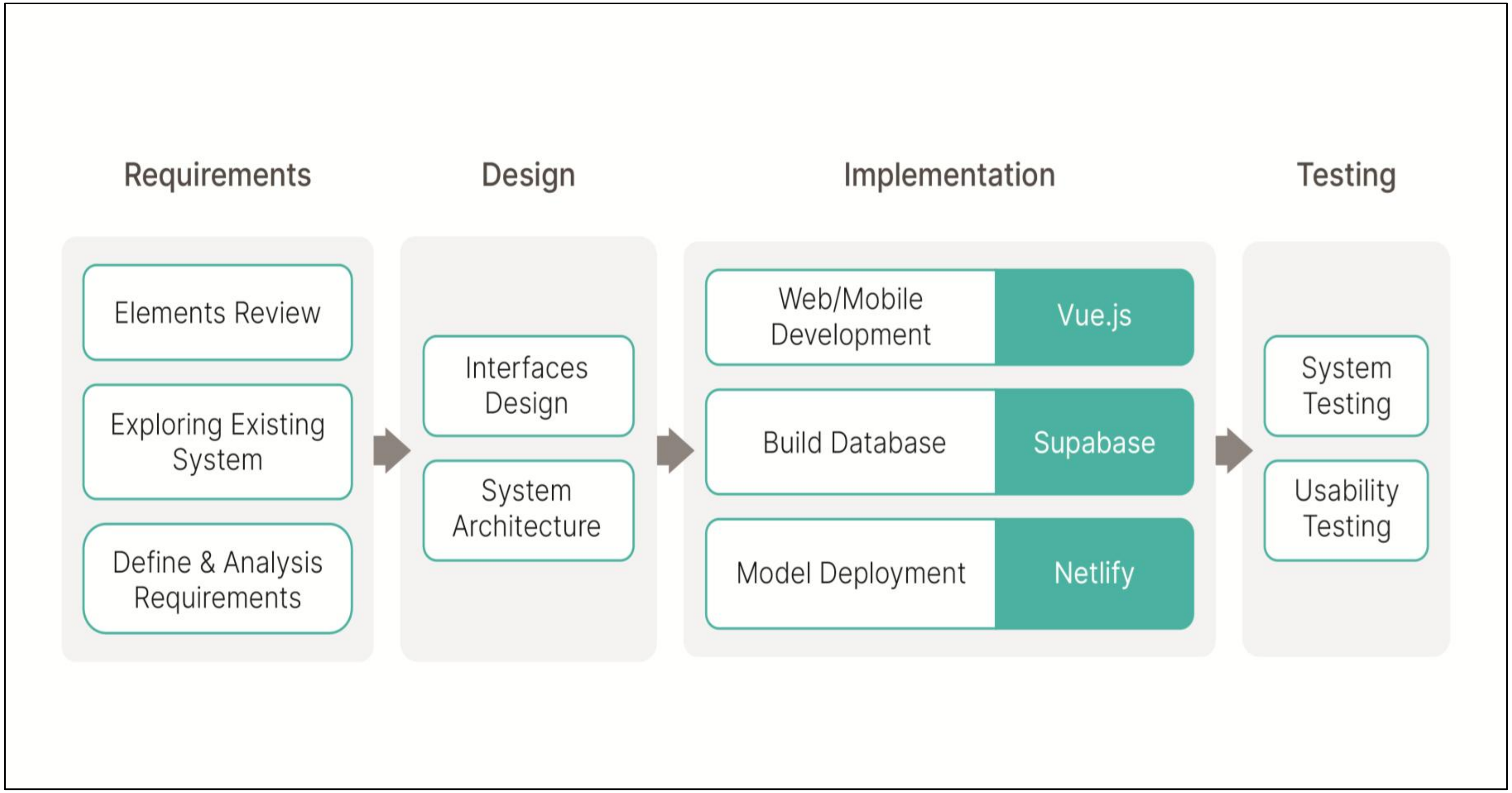

Figure 3.4 The Development Process of the Behavioural Occupational Safety Culture Application (BOSCA).

a) System Requirements

The first step involved an in-depth exploration of safety culture elements specific to the oil and gas industry. This comprehensive analysis served as the foundation for understanding the key factors influencing safety culture within the sector. A survey was conducted among subject matter experts representing four key stakeholder groups: safety and health practitioners, authorities, academicians, and management. The survey aimed to capture each group's preferences regarding which safety culture elements should be prioritised in the oil and gas industry.

The analysis of survey results indicated that each stakeholder group had distinct preferences for prioritising safety culture elements. These variations in preferences underscore the need for a flexible and adaptable approach to safety culture enhancement in the industry. After thoroughly analysing the stakeholder preferences, it was determined that behavioural elements should be prioritised. These behavioural elements emerged as the key drivers for enhancing safety culture in the oil and gas industry. The sub-elements of the prioritised behavioural elements are visually represented in Table 3.6.

Table 3.6
Behavioural Safety Culture Elements

Module	**Objective**	**Rationale**
Module 1: Management Commitment	To demonstrate and reinforce management's commitment to safety.	This design allows management to efficiently monitor and analyse safety performance, make informed decisions, and take proactive measures to maintain a safe working environment.
Module 2: Safety Commitment	To encourage individual and collective commitment to safety.	This design facilitates efficient and thorough reporting of safety incidents and near-misses, encouraging a proactive approach to workplace safety and fostering a culture of continuous improvement.
Module 3: Safety Ownership	To foster a sense of ownership.	Tool for conducting and recording safety audits, facilitating a thorough and systematic approach to workplace safety management.
Module 4: Safety Training	To provide continuous and accessible training.	Accessing and managing safety training materials, promoting continuous learning and improvement in workplace safety.

Module	Objective	Rationale
Module 5: Safety Communication	To ensure clear and effective communication of safety information.	Accessing and managing real-time safety alerts and notifications, ensuring employees stay informed and can respond promptly to safety-related updates.
Module 6: Reward Recognition	To recognise and reward safe behaviour and achievements.	Platform for employees to nominate their peers for safety awards, promoting a culture of recognition and appreciation within the workplace
Module 7: Safety Investment	To demonstrate and track investment in safety.	Interface for employees to submit and track their safety improvement suggestions, fostering a culture of continuous improvement and proactive safety management within the workplace.
Module 8: Safety Competency	To ensure all employees have the necessary skills and knowledge for safety.	For employees to take regular competency assessments, track their progress, and receive feedback to ensure they have the necessary skills and knowledge for safety

After finalizing the safety culture element and the rationale of each element, the functionalities of BOSCA were specified for both actors as portrayed in the use case diagram in Figure 3.5. The system described in this study integrates several common use cases that are applicable to both the *User* and *Admin* actors, ensuring a cohesive and functional experience for all users. These use cases include essential functions such as registering, logging in, filling out forms, uploading and viewing certificates, receiving notifications, and managing evaluations and hazards. The "Register" use case enables both users and admins to create an account within the mobile application. This process involves entering registration details, which the system validates. Upon successful validation, an account is created, allowing the actor to log in. If the system detects an existing account, an error message is displayed. The "Login" use case provides a secure method for both the user and admin to access the system by entering credentials that the system authenticates against stored data. Successful authentication grants access, while invalid credentials trigger an error message.

In addition, the system includes the "Fill Declaration Form" and "Fill Verification Form" use cases, which allow users to submit and verify required information through forms. Admins are then able to review the submitted data to ensure accuracy. The "Upload Photo" use case enables users to upload images for identification or documentation, with admins reviewing the uploaded photos. The "Pin Location" use case allows users to share their current location, which admins can access for monitoring purposes. This functionality requires location services to be enabled on the user's device. The "Upload Certificate" use case allows users to upload certifications for record-keeping or verification, and the "View Certificate" use case permits both users and admins to access and view these uploaded certificates. The system ensures that certificates are readily available for viewing after they are uploaded. Furthermore, the "Get Notification" use case provides both users and admins with alerts about important updates, tasks, or messages via email, ensuring that key information is communicated effectively. The "View Evaluation" use case allows admins to assess and evaluate users, with the results being made available to users to view their performance outcomes. The system facilitates this process by making evaluation marks accessible once the admin completes the assessment. Additionally, the "Update Hazard" use case enables users to report workplace hazards, which admins can review and manage, playing a crucial role in maintaining workplace safety.

Finally, the "Download Document" use case allows users to download necessary documents, while admins manage the uploading of these documents to the system. The "Fill Suggestion Form" use case enables users to submit suggestions for improvements, which admins can review for potential action or feedback. This suite of use cases is designed to provide a comprehensive and user-friendly experience for both users and admins, ensuring that all critical functionalities are covered while maintaining robustness and reliability in handling various scenarios.

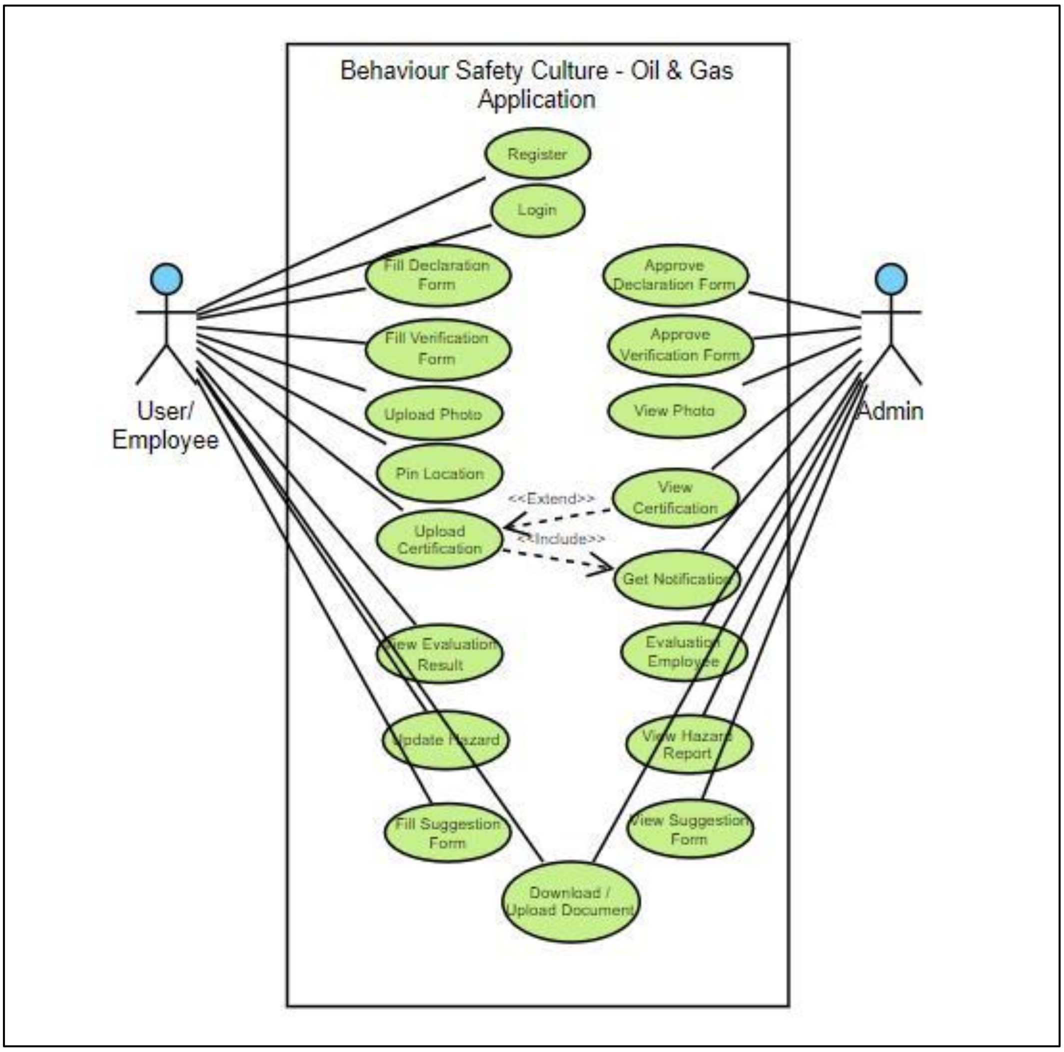

Figure 3.5 The Diagram Depicts the Use Case Diagram for the Behaviour Safety Culture - Oil & Gas Application.

b) System Architecture

The BOSCA architecture is designed to ensure robust and seamless interactions between users and the system. As illustrated in Figure 3.6, the BOSCA architecture is built on a multi-layered approach, integrating various components to deliver an efficient and secure user experience. The user interface layer serves as the primary access point for both users and admins. Users interact with the system via a progress web application, which must be installed on their devices. This application provides functionalities such as account registration, login, form submission, certificate management, and hazard reporting. Admins access the system through a specialized dashboard, allowing them to manage user data, review reports, and perform audits. At the core of the BOSCA is the application layer**,** which handles the business logic and operations essential to the system's functionality. This layer includes modules for authentication and authorization, ensuring that only authorized users can access specific services. The business logic layer processes user inputs, such as health examination data, field verification results, and safety audit records. The notification module alerts users and admins about important updates, while the data processing module manages tasks like photo uploads and location pinning. The reporting module facilitates the generation of reports, including audit results and hazard identification summaries. All user and system data is stored and managed within the data layer, which comprises a relational database and a file storage system. The database securely stores user profiles, inspection records, training certifications, and hazard reports. The file storage system manages files such as uploaded photos and certificates, ensuring they are accessible when needed.

The integration layer facilitates communication between the user interface and the application layer through an *API Gateway*. This layer ensures that data flows seamlessly between the front-end application and the back-end services. Additionally, it allows for integration with external services, such as email servers for notifications and third-party systems for enhanced functionality. The BOSCA architecture relies on an independent server, which users remotely connect to via the internet. This setup requires users to have a stable internet connection to access database-related services and perform inspections. The use of an independent server allows for centralised management of data and services, ensuring that all operations are conducted securely and efficiently. This architecture is critical to supporting the BOSCA's mission of promoting a strong safety culture across various industries.

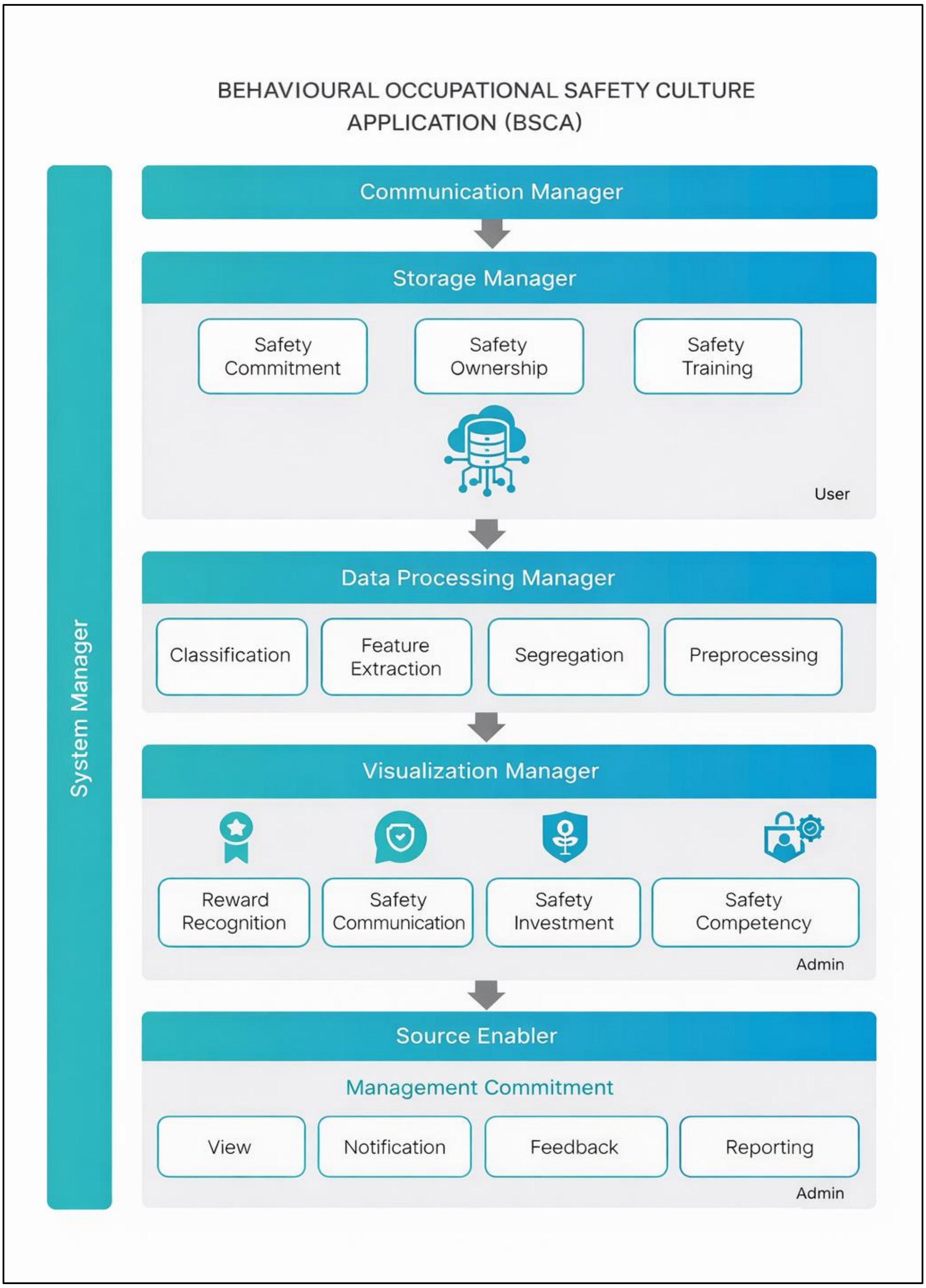

Figure 3.6 Framework of the Behavioural Occupational Safety Culture Application (BOSCA)

c) Database

The BOSCA database structure was meticulously designed using a class diagram in unified modelling language (UML) notation. The class diagram serves as a graphical representation that captures the structural components of the database, including classes, attributes, and relationships, providing a detailed overview of the application's data organisation. Figure 3.7 depicts the Entity-Relationship Diagram (ERD) for the BOSCA. This diagram outlines the key entities within the application and the relationships between them, providing a comprehensive overview of the data structure and interaction mechanisms.

The user entity contains attributes such as user ID, user name, user email, user phone no, user role and user pass. This entity is responsible for user registration and login processes within the system. The admin entity, which includes attributes like admin ID, admin name, admin email, admin phone number, and admin pass, provides higher-level access for managing user accounts and sending notifications. The login entity manages the authentication process and records login sessions with attributes such as login ID, user ID, login time, logout time, and admin pass, including methods for user authentication and sending notifications. The incident report entity represents incidents reported within the system and includes attributes such as report ID, incident date, incident type, incident description, incident location, and incident reported by, allowing users to file incident reports. The observation entity captures observations made by users, with attributes like observation ID, observer ID, observed behaviour, observation time, observation location, and observation comment and includes methods to log observed behaviours. The behaviour entity details specific behaviours observed or recorded, including behaviour ID, behaviour type, and behaviour description and is linked to observation logs for categorising and managing behaviour-related records. Additionally, the safety audit entity manages safety audits, with attributes such as audit ID, audit date, audit findings, and action required, supporting the documentation of findings. The training entity represents the training programs scheduled and completed, with attributes such as training ID, training name, training date, trainer ID and training completion status, and includes methods for scheduling training sessions and recording completion. The notification entity manages notifications within the system, with attributes like notification ID, user ID, notification date, and notification message and is responsible for sending notifications to users.

Firebase was utilised to build the database due to its suitability for real-time applications (Tanna, 2024, Kumuar, 2018 and Achutan et al., 2024). Its integration enables seamless synchronization of data across devices, supporting critical functionalities such as incident reporting, safety audits, training management, and user notifications. This database structure enhances the system's efficiency and adaptability to changing requirements, providing a solid foundation for the BOSCA application's operations.

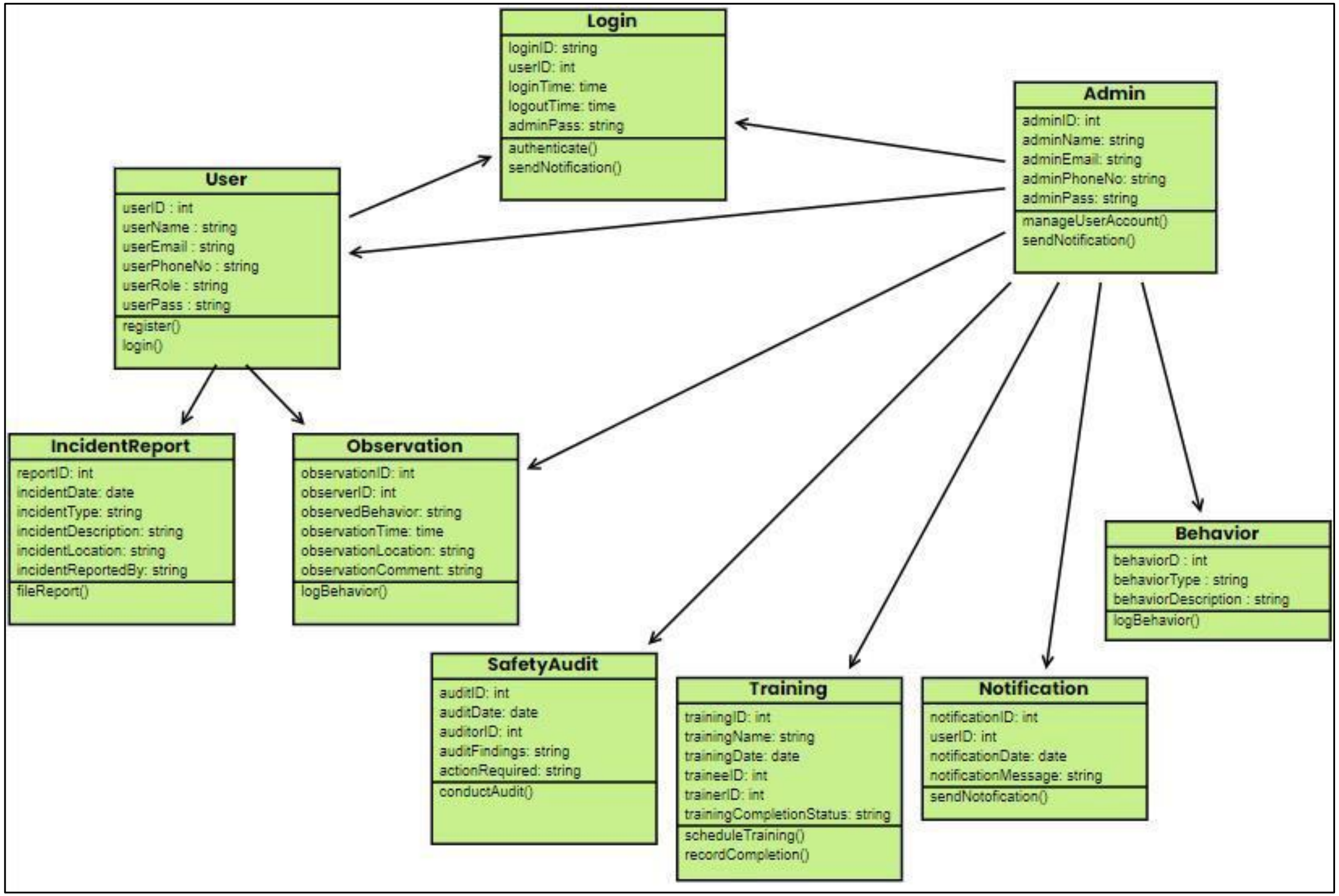

Figure 3.7 Entity-Relationship Diagram (ERD) for the BOSCA

d) Application Development

The real-time monitoring tool for safety culture behaviour in the oil and gas industry was developed with a focus on cross-platform accessibility and efficient data management. Initially built using Flutter, a leading cross-platform framework by Google, the application was designed to create natively compiled apps for both iOS and Android from a single codebase. However, considering the versatility and benefits of Progressive Web Applications (PWAs), the mobile application can also be substituted with a PWA, which offers similar advantages with additional flexibility. User Interface (UI) Design was prioritised to ensure a seamless and intuitive experience. The UI was developed using Flutter's widget library, but with a PWA, the design could be further optimized to work directly within a web browser across multiple devices, including desktops. This would eliminate the need for users to download and install the application, while still offering an app-like experience when added to the home screen on mobile devices.

Core features such as real-time data collection allow field inspectors and safety officers to submit observations directly from the field, with data immediately uploaded to a central database. Geolocation tracking, initially integrated using Google API, remains a key feature in both the mobile app and the PWA, ensuring precise location tagging of reports. The PWA can also support offline functionality, enabling users to record observations without internet connectivity and synchronize data once the connection is restored. The PWA's automatic update feature ensures that all users are always using the latest version of the application without the need for manual updates, further simplifying maintenance. Additionally, the application implements robust security measures, including end-to-end encryption and secure user authentication, whether accessed as a mobile app or a PWA. On the backend, the application is integrated with a centralised server that ensures high availability and scalability, capable of handling large volumes of data typical in the oil and gas industry. The server communicates with the application via RESTful APIs, ensuring efficient data exchange, regardless of whether the front-end is a native mobile app or a PWA.

e) Frontend and Backend Architecture

The BOSCA application was developed with a clear distinction between frontend and backend functionalities. The frontend designed using Vue.js and Flutter delivered the user-facing experience, including modules for hazard reporting, training, feedback notifications, and competency tracking. These modules were optimised for cross-device accessibility and responsive interaction. The backend, developed using *Supabase* and Firebase, managed secure data processing, API connections, user authentication, and storage. It supported key backend services such as incident record logging, notification delivery, and reporting module integration. User testing during the validation phase focused solely on the frontend modules. Participants were engaged in evaluating interface usability, functionality access, and task flow navigation, while backend operations were tested internally to verify performance, data handling, and system integrity.

3.3.7 Phase 7: Expert-Based Content and Design Validation of the Behavioural Occupational Safety Culture Application (BOSCA)

a) Study Design

This study employed a cross-sectional Design and Development Research (DDR) approach to guide the systematic creation and validation of the *Behavioural Occupational Safety Culture Application* (BOSCA). The DDR framework was selected because it integrates both theoretical and practical dimensions of research enabling the translation of behavioural safety concepts into a functional digital platform (Guo et al., 2023 and Del et al., 2025)). The design process comprised two key phases: (1) development, which involved conceptual modelling, content formulation, and interface design based on established behavioural, instructional, and technology acceptance theories; and (2) validation, which used expert consensus to assess the accuracy, usability, and pedagogical soundness of BOSCA. This methodological approach ensured that the development process was evidence-based, iterative, and user-centred, allowing theoretical constructs to be operationalised into a practical, contextually relevant tool for strengthening behavioural safety culture within the oil and gas industry.

b) Framework Development

The development of the *Behavioural Occupational Safety Culture Application* (BOSCA) was structured in three main stages: (1) content identification, (2) design and interface development, and (3) validation. This sequential framework ensured a systematic transformation of behavioural safety theories into an applied digital intervention tailored for the oil and gas industry.

Content Identification: A comprehensive literature analysis was conducted to identify key components of safety culture encompassing behavioural, situational, and psychological dimensions relevant to high-risk industries. Emphasis was placed on the behavioural dimension, which has been shown to exert the strongest influence on safety performance outcomes. The conceptual framework and prioritised elements used in this study were previously developed and published by the research team (Rahim et al., 2024), based on a structured review and expert ranking using the Analytic Hierarchy Process (AHP) (Rahim et al., 2024). The published framework identified management commitment, safety ownership, safety communication, safety competency, and reward and recognition systems as the highest-ranked behavioural components driving safety culture maturity in the oil and gas sector.

Design and Interface Development: The design and interface development were guided by the Model of Internet Interventions to ensure alignment between user needs and learning objectives. BOSCA was developed as a Progressive Web Application (PWA) incorporating features such as offline functionality, real-time notifications, and cross-device compatibility to enhance accessibility for both field and office users. The visual and structural components including colour palette, typography, and layout consistency are detailed in Table 3.7, which outlines the application of the digital facilitation model across eight interface characteristics.

Table 3.7
Application of the Digital Facilitation Model in the BOSCA

No.	Characteristic	Application
1	Appearance	The colour palette consisted primarily of blue, grey, and white tones, with accent colours such as red, green, and orange used to differentiate functional categories, including alerts, training modules, and reward recognition. The interface applied a responsive design to ensure compatibility across various devices, including desktops, laptops, tablets, and smartphones. The Nunito typeface was selected for its readability and suitability for digital environments. Font sizes were applied hierarchically, with 36 points for main headers, 20 and 14 points for subheadings, and 12 points for body text. Illustrative elements and icons were obtained from Freepik.com under a premium copyright-free license to maintain visual coherence and professional quality. The mobile application background was white because it provides a clean website and a colour of purity and aspiration (Alnasuan, 2016). In addition, the use of a white background provides a colour contrast on the web (Gu et al., 2016). The font colours vary depending on the headline and text. This helps users to identify the topic of the content easily.
2	Behaviour	New users are required to register and create an account before accessing the BOSCA mobile application. The module is designed to enhance organisational behavioural safety culture by promoting reporting culture, safety communication, training, audits, competency, reward and recognition, safety initiatives, and performance monitoring.
3	Burdens	The mobile application content was divided into two sections: one interface for management to view safety culture performance, and another for employees to access the remaining modules.
4	Contents	The content was developed based on a literature review and expert evaluation of preferred safety culture behavioural sub-elements.
5	Delivery	Content was delivered through text, infographics, attachments, and videos.
6	Message	The content was presented in plain language, avoiding safety jargon. Text, videos, and infographics were written in a conversational tone to enhance user understanding.
7	Participation	To encourage user engagement, a conversational tone was used throughout the content. Real-time notifications were sent to users to promote continued use, and completion of end-of-unit activities was required.
8	Assessment	The safety audit included an assessment of individual safety compliance, allowing HSE administrators and management to evaluate users' safety culture performance. The management dashboard provides an overview of the overall performance of behavioural safety culture elements.

The theoretical foundation and preliminary design framework for BOSCA were derived from a previously accepted publication that outlined the conceptual modelling and interface principles supporting this study (Rahim et al., 2024). That publication provides detailed justification of the digital behavioural safety model and its integration with instructional and technology acceptance theories, ensuring methodological transparency and validation of the current development process. To enhance usability, the design integrated behavioural and instructional frameworks, specifically the Unified Theory of Acceptance and Use of Technology (UTAUT) and Flow Theory, to promote intuitive interaction and sustained engagement. Table 3.8 illustrates how the UTAUT model's four predictors, namely performance expectancy, effort expectancy, social influence, and facilitating conditions, were embedded within BOSCA's functional design. The interface incorporated interactive dashboards, real-time alerts, and progress-tracking modules, supporting both managerial monitoring and employee learning.

Table 3.8
Application of the UTAUT Model in the BOSCA

Predictors	Definition	Application
Performance expectancy	The extent to which an individual believes that using the system enhances their job performance.	The mobile application presents information aimed at enhancing users' safety management systems and compliance. Content is segmented into smaller parts and structured into sections to minimise cognitive load.
Effort expectancy	The extent to which the system is perceived as easy to use.	Users are required to log in before accessing the system. The homepage provides functional buttons to facilitate usability.
Social influence	The extent to which an individual perceives that significant others expect them to use the system.	The mobile application is accessible to all user groups, including site employees, office staff, and management.
Facilitating conditions	The extent to which an individual believes that the organisation's technical infrastructure adequately supports system usage.	The application includes a communication platform for user interaction with safety personnel, feedback submission to management, and a notifications feature.

Validation: The final development stage involved structured validation using the Fuzzy Delphi Technique (FDT) to assess BOSCA's content accuracy, interface design, interactivity, and instructional strategies. Through this process, experts assessed whether the implemented BOSCA features accurately reflected their intended theoretical functions such as usability, user engagement, and instructional sequencing thereby providing empirical confirmation of theory operationalisation rather than theoretical assertion alone. Figure 3.8 presents the *User Experience (UX) design principles* applied within BOSCA's platform, demonstrating how the *Training Module* and *Competency Dashboard* facilitate engagement through feedback loops and progress indicators. Figure 3.9 further illustrates the integration of *Bloom's Revised Taxonomy* and *Gagné's Nine Events of Instruction* within BOSCA's instructional framework, ensuring that learning progresses from foundational knowledge acquisition to behavioural reinforcement. Together, these stages established BOSCA as a validated, theory-driven digital intervention capable of reinforcing behavioural safety culture through structured learning, real-time communication, and continuous performance monitoring.

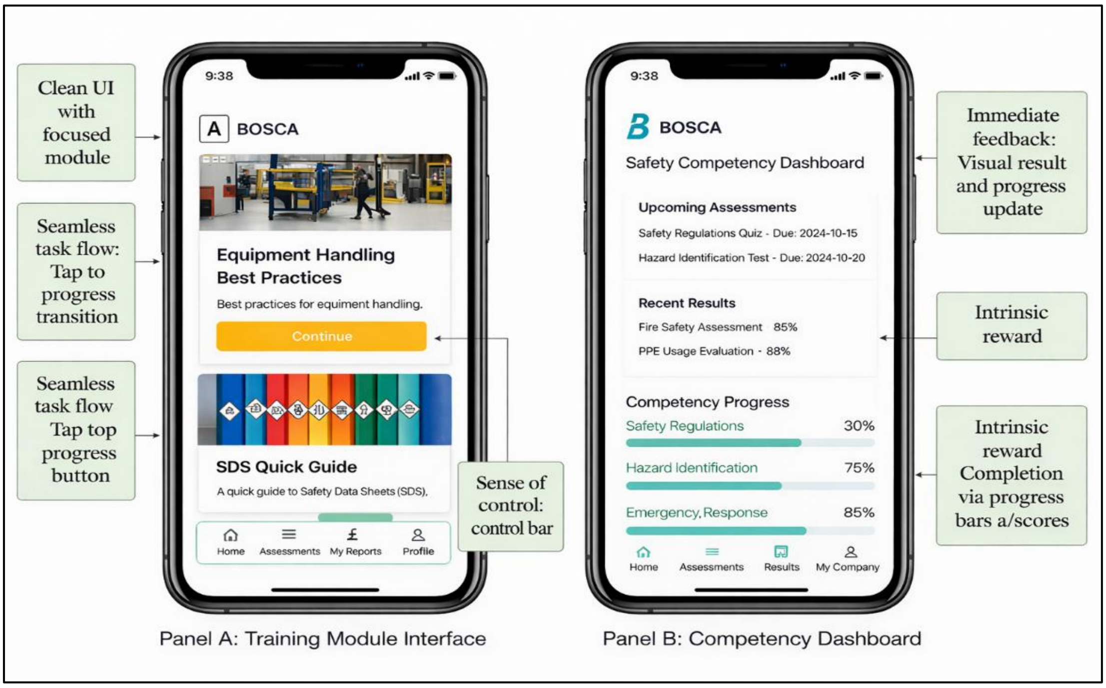

Figure 3.8 User Experience (UX) Design Principles Embedded in the BOSCA Mobile Learning Platform. (A) The Training Module Interface emphasizes clarity and seamless task flow through modular learning cards, enabling users to initiate or resume activities intuitively. (B) The Competency Dashboard demonstrates feedback-driven engagement, displaying progress indicators, assessment results, and intrinsic motivation cues through visual completion metrics.

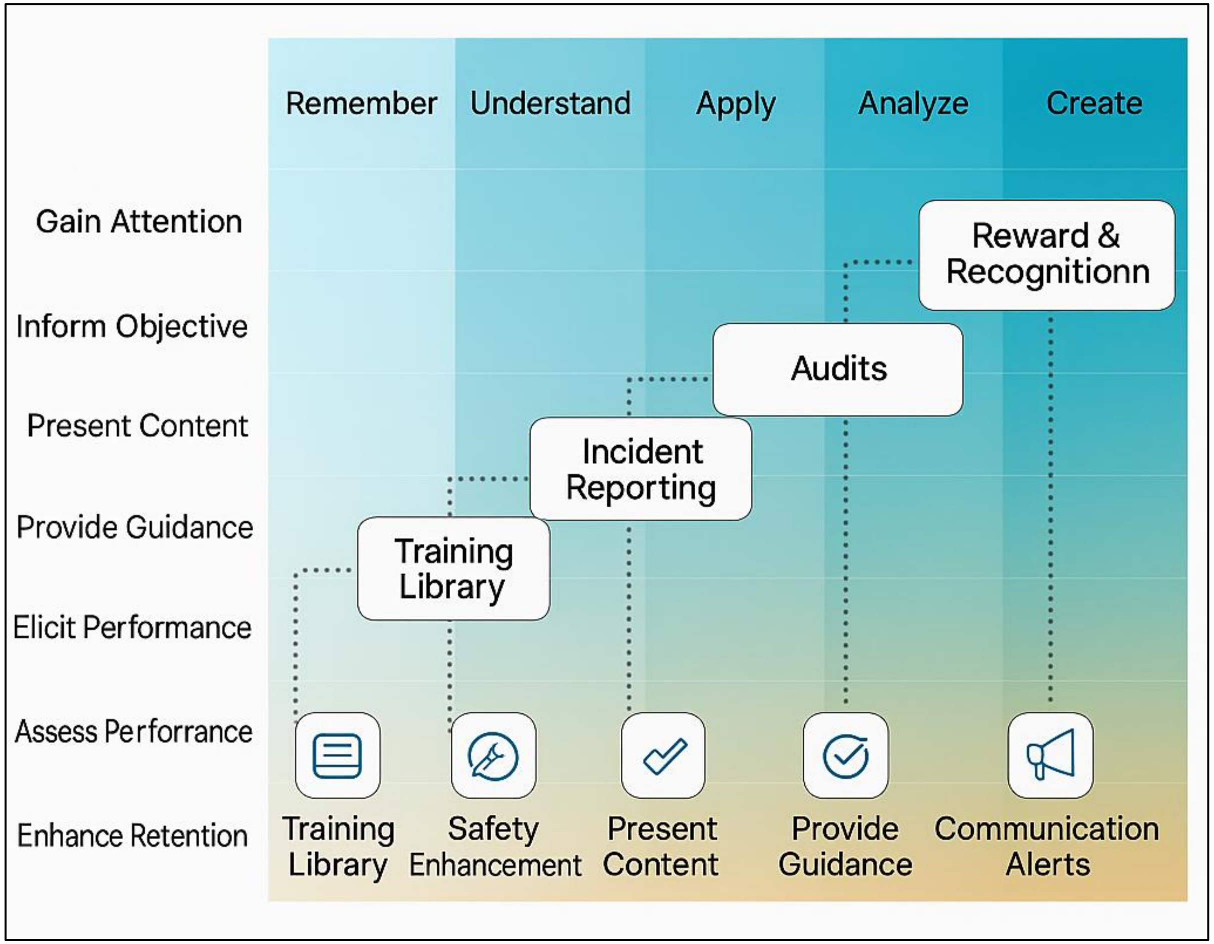

Figure 3.9 Instructional Alignment of BOSCA Interface Integrating Bloom's Revised Taxonomy and Gagné's Nine Events of Instruction. The matrix illustrates how BOSCA modules correspond to progressive cognitive domains (from "Remember" to "Create") and instructional phases (from "Gain Attention" to "Enhance Retention"), demonstrating a structured pathway from knowledge acquisition to performance mastery within safety learning.

c) Validation and Expert Panel

A purposive sampling strategy was employed to recruit 15 multidisciplinary experts for the validation of BOSCA. All experts possessed a minimum of five years of professional experience in occupational safety and health (OSH), primarily within the oil and gas industry. This ensured that participants had the technical depth and contextual understanding necessary to assess the relevance and practicality of the digital safety culture application. The expert panel represented diverse backgrounds, including management, executive, and operational personnel, as well as academics and safety regulators, providing a balanced and comprehensive evaluation of BOSCA from strategic, administrative, and field-level perspectives.

The validation process involved expert evaluation across four principal domains: thematic content, interface design, interactivity, and instructional strategies. The thematic content domain assessed the clarity, comprehensiveness, and relevance of BOSCA's behavioural safety components to industry practices. The interface design domain evaluated visual presentation, layout coherence, and navigational flow to ensure accessibility and ease of use. The interactivity domain examined user engagement features such as feedback, communication mechanisms, and response functionality. Lastly, the instructional strategies domain assessed the pedagogical soundness of BOSCA's learning structure, including the alignment of instructional sequences with behavioural change principles and digital learning frameworks. This multi-domain approach ensured a holistic evaluation encompassing both functional and theoretical aspects of the application. The role of the expert panel was limited to content, design, interactivity, and instructional validation, and did not involve system usage as end users or exposure within operational work environments. The diversity of expertise was intended to enhance the breadth and credibility of expert judgment rather than to serve as a measure of statistical reliability, which was instead addressed through established Fuzzy Delphi consensus criteria.

The Fuzzy Delphi Technique (FDT) was utilised to quantify expert consensus regarding BOSCA's content validity and usability. Each expert rated all items using a seven-point linguistic scale ranging from *strongly disagree (1)* to *strongly agree (7)*. Data were analysed using triangular fuzzy numbers to determine three parameters: the threshold value (d) representing variation among expert judgments, the percentage of consensus reflecting the proportion of agreement, and the defuzzification value (A) denoting the overall acceptance level. Items were considered valid when they met the predetermined thresholds of $d \leq 0.2$, consensus $\geq 75\%$, and $A \geq 0.5$. This structured process provided an objective and replicable measure of expert agreement, confirming the robustness and credibility of BOSCA's design and content.

d) Statistical Analysis

The data analysis was conducted systematically using Microsoft Excel software. The Fuzzy Delphi method requires two main prerequisites: the triangular fuzzy number and the defuzzification process. For the triangular fuzzy number to be accepted, two conditions must be met: (1) the Threshold value (d) must be less than or equal to 0.2 and (2) there must be a sufficient percentage of expert agreement. The first condition is satisfied when the calculated threshold value is ≤ 0.2. The acceptance thresholds applied in the Fuzzy Delphi Technique (FDT) were determined based on established methodological conventions in Delphi and fuzzy decision-making research (Haghighat et al., 2024). The threshold value *($d \leq 0.2$)* was adopted to indicate a sufficiently low level of variation among expert judgments, reflecting strong consensus and minimal dispersion of opinions. This cut-off has been widely used in FDT studies to ensure stability and agreement across expert responses. In line with traditional Delphi methodology, an expert consensus level of $\geq 75\%$ was selected as the minimum criterion for acceptance, representing substantial agreement among panel members. Additionally, the defuzzification value *($A \geq 0.5$)* was applied using an α-cut approach, where values equal to or exceeding 0.5 indicate acceptable importance and agreement of the evaluated item. Collectively, these thresholds were chosen to provide a conservative and reproducible validation framework, ensuring that only items with strong expert support were retained.

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]}$$

Where:

- m_1, m_2, m_3 = Triangular fuzzy numbers from Expert A
- n_1, n_2, n_3 = Triangular fuzzy numbers from Expert B
- d = Threshold value between two experts' responses

The second requirement for the triangular fuzzy number involves the percentage of expert agreement. According to the traditional Delphi technique, expert consensus is considered acceptable if it exceeds 75% (Giannarou et al., 2014). In contrast, the defuzzification process involves determining the fuzzy score value (A) using an α-cut value of 0.5 (Tang et al., 2010 and Bodjanova, 2006). If the resulting fuzzy score (A) is equal to or greater than 0.5, the measured item is accepted; otherwise, if the value is less than 0.5, the item is rejected. The fuzzy score (A) was calculated using the following formula:

$$A = \frac{1}{3}(m_1 + m_2 + m_3)$$

Where:

- m_1 = the lowest value (minimum) of the Triangular Fuzzy Number
- m_2 = the most likely value (modal)
- m_3= the highest value (maximum)

The triangular fuzzy numbers were systematically derived following the evaluation of collected data across five components: themes, sub-themes, presentation interface design, interactivity interface design, and instructional strategies. The use of these established cut-off values enhances the comparability of the present findings with prior FDT-based validation studies and strengthens the methodological robustness of the expert validation process.

3.4 Ethical Considerations

This study was conducted in accordance with the ethical principles governing research involving human participants at Universiti Teknologi MARA (UiTM). Ethical approval was granted by the UiTM Research Ethics Committee (REC) [Reference: REC/07/2023 (PG/MR/251)] on 21 July 2023. All expert participants were fully informed of the study objectives, procedures, and their right to voluntary participation, and written informed consent was obtained prior to data collection. Participant confidentiality and data privacy were rigorously maintained throughout the validation process. No personally identifiable information was collected, stored, or displayed, and all data were used solely for research purposes. Within the BOSCA platform, privacy protection was further supported through role-based access control, restricted visibility of individual-level data, and the presentation of aggregated or anonymised indicators on management dashboards. The system operates on rule-based monitoring mechanisms and does not perform behavioural inference, profiling, or automated decision-making. Expert validation confirmed the appropriateness of these privacy and data protection safeguards at the design level, ensuring alignment with organisational data governance policies.

3.4.1 Expert Panels and Conflict of Interest

Expert panels involved in CVI, CVR, and Fuzzy Delphi evaluations were required to declare any potential conflicts of interest. No conflicts were reported. Experts were informed that their feedback would be aggregated and anonymised, and that no contribution would be linked to their professional position or employer. This ensured freedom of expression and genuine expert judgment. Because the study involved the development of a digital application (BOSCA), additional ethical safeguards were implemented. Prototype testing involved only interface usability assessments, without capturing behavioural performance data from participants. Participants were informed that the system did not evaluate or rate their real job performance, and no organisational records would be accessible through the application. Interface reviews were conducted using anonymised test accounts to protect privacy and prevent any accidental data exposure.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

This chapter provides a comprehensive synthesis of the study's three major aims, collectively offering an evidence-driven understanding of safety culture in the oil and gas industry and advancing methodological and practical tools for its assessment. The findings begin with a systematic examination of global safety-culture research, revealing how behavioural, situational, and psychological dimensions continue to shape safety outcomes in an industry undergoing rapid digital transformation. Across 33 studies, the review identifies dominant predictors such as safety rules, safety ownership, risk perception, communication, and training, while also highlighting emerging themes linked to human–technology interaction, digital readiness, and organisational maturity. These insights emphasize that effective safety culture is not only a behavioural construct, but a socio-technical system influenced by technology adoption, regulatory frameworks, and workforce adaptability.

The chapter then transitions into the development and validation of a specialised Safety Culture Questionnaire (SCQ), designed to address gaps identified in existing tools. Rigorous psychometric evaluation including face validity, Content Validity Index (CVI), Content Validity Ratio (CVR), and reliability testing demonstrates that the SCQ is both robust and industry-specific, with strong internal consistency across psychological, situational, behavioural, and preference dimensions. This tool offers a structured means for organisations to diagnose safety culture strengths and weaknesses, enabling targeted interventions aligned with operational priorities and risk environments. Building on the validated instrument, the final part of the chapter explores stakeholder preferences using structured comparison methods to decode which safety culture elements are considered most influential. The results show a consistent prioritisation of behavioural drivers such as management commitment, safety ownership, and communication reflecting the industry's recognition that technology alone cannot ensure safety without strong human engagement. Situational and psychological aspects, including environmental conditions, job satisfaction, risk perception, and safety knowledge, also emerge as pivotal, underscoring the need for an integrated approach that aligns human factors with technological and organisational systems. Overall, the chapter illustrates a clear trajectory: from understanding global patterns and gaps in safety culture research, to developing a validated measurement tool, to identifying stakeholder-driven priorities for intervention. Together, these components form a coherent evidence base that advances both theoretical understanding and practical strategies for strengthening safety culture in high-risk, technologically complex environments.

4.2 Aim 1: Systematic Exploration of Safety Culture in the Oil and Gas Industry[4]

The oil and gas industry is a cornerstone of global energy production, yet it operates in one of the most hazardous environments, where safety remains a persistent challenge (Rodhi et al., 2017). The high-risk nature of this industry arises from its complex operations, advanced technologies, and the dynamic interplay between human, technological, and organisational factors (Al-Rbeawi, 2023). These challenges underscore the need to cultivate a robust and adaptive safety culture that integrates human vigilance with technological precision to prevent accidents, safeguard personnel, and protect assets (Naji et al.,2021 and Rasmussen, 2022). In recent years, technological transformation has redefined the foundations of safety management in the oil and gas industry. The advent of digitalization, automation, and AI-assisted safety monitoring systems have shifted safety paradigms from reactive to predictive models. Technologies such as real-time sensor analytics, predictive maintenance algorithms, and drone-based inspections now enable early detection of risks and near-miss events. While these advancements enhance efficiency and responsiveness, they also introduce new challenges including workforce adaptation, data governance, and human–machine coordination necessitating a renewed focus on behavioural and organisational adaptability within safety culture frameworks.

Despite the proliferation of technological solutions, the human dimension remains the critical determinant of safety outcomes (Bisbey et al., 2021 and Vierendeels

[4] Hafiz Rahim, Rahmat Dapari, Mohd Azuraidi Osman, Nazri Che Dom (2025). Bridging Human and Technological Dimensions: A Systematic Exploration of Safety Culture Transformation in the Oil and Gas Industry. *Humanities and Social Sciences Communication.* (Submitted 5 Nov 2025: *Under review*)

et al., 2018). A safety system can only be as resilient as the behavioural, situational, and psychological foundations that support it. However, existing research often isolates technical innovation from human and organisational responses, overlooking how safety culture evolves alongside digital transformation (Atikasari et al., 2022 and Nævestad et al., 2021). This gap highlights the need for a holistic understanding of how workers, leaders, and institutions internalize and operationalise technology-driven safety mechanisms. The societal and policy implications of this shift are profound. As digital technologies reshape workplace safety norms, regulatory bodies and corporate governance systems must adapt policies to ensure ethical implementation, transparency, and accountability. Effective integration of safety technologies demands not only technical readiness but also cultural acceptance and policy alignment that bridge the divide between innovation and human behaviour. In this regard, the oil and gas sector serves as a microcosm of broader socio-technical change where technology adoption, human engagement, and policy evolution must progress in unison to sustain safety performance.

The primary objective of this study is to conduct a thematic and systematic exploration of the behavioural, situational, and psychological factors influencing safety culture in the oil and gas industry. Guided by the question, *"What are the key factors influencing safety culture studies conducted in the oil and gas industry?"*, this review aims to synthesize evidence across diverse contexts to illuminate underlying patterns and actionable insights. By examining how human and technological dimensions co-evolve, this study offers lessons that extend beyond the oil and gas sector. Insights derived from this review can inform cross-sectoral applications, including manufacturing, construction, and emerging fields such as renewable energy and autonomous operations where technology integration similarly redefines safety expectations. Ultimately, this research contributes to the ongoing discourse on how behavioural safety culture adapts to technological change, enabling safer, smarter, and more socially responsive industrial ecosystems.

4.2.1 Study Characteristics and Quality Assessment

The systematic review encompassed thirty-three peer-reviewed studies published between 2013 and 2024, reflecting a global effort to understand and strengthen safety culture within the oil and gas industry during a decade of accelerating technological change. The quality assessment, summarised in Table 4.1, evaluated adherence to twelve standardised methodological criteria. The quality assessment results indicate that twenty-eight of the 33 selected studies (84.8%) satisfied at least ten of the twelve quality assessment criteria, suggesting that the majority of the included studies demonstrated good methodological quality and were suitable for inclusion in the thematic synthesis. Only a small number of studies met fewer than ten criteria; however, these studies were retained as they still provided relevant empirical evidence related to safety culture dimensions and elements. Mixed-method and cross-sectional designs were the most prevalent, illustrating a maturing methodological landscape in safety culture research. These designs enabled triangulation of quantitative indicators such as safety performance metrics and human-technology interaction (HTI) indices with qualitative insights from worker perceptions, managerial practices, and policy frameworks. Despite overall methodological strength, some limitations persisted, particularly in older studies that lacked clear documentation of bias control, ethical approval, and data transparency. Such limitations underscore the importance of standardised reporting protocols and open data practices, especially as digital monitoring tools become integral to safety management systems. The consistent methodological rigor observed in recent studies (post-2020) reflects growing awareness of the importance of integrating behavioural and technological perspectives when examining safety culture evolution in digitally transforming industries.

Table 4.1
Quality Assessment of Research Articles

	Masudin et al.	Rocha et al.	Wang et al	Hien et al	Pati S.	Ehiaguina et al.	Parasram et al.	Benevides	Payne et al.	Ofori et al.	McSweeney et al	Kamynina et al.	Putri et al.	Al-Mekhlafi et al.	Fabiano et al.	Mohamad et al.	Guzman et al.	Kalteh et al.	Rasmussen & Ahsan	Iqbal et al.	Liya et al.	Al-Mekhlafi et al.	Naji et al.	Alomari et al.	Nana et al.	Iqbal et al.	Al Mazroueiet al.	Quoquab et al.	Ebrahimi et al.	Phusavat et al.	Laplonge	Nair & Siddiqui	Chen et al
QA 1	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
QA 2	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟣	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟣	🟢	🟢
QA 3	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟣	🟢	🟢	🟢	NA	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
QA 4	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🟢
QA 5	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴
QA 6	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	NA	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟣	🔴	🔴	🔴	🔴	🔴	U	U	NA	🔴	🟣	🔴	🔴
QA 7	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	NA	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	U	🔴	🟢	🟢	🟢	🟢	🟢
QA 8	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	NA	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	NA	🟢	🟢
QA 9	NA	NA	🟢	NA	NA	NA	NA	🟣	NA	NA	NA	🔴	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	🟢	U	🟢	NA	NA	NA	NA
QA 10	NA	NA	NA	NA	NA	NA	NA	🟣	NA	NA	NA	🟢	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	🟢	🟢	🟢	NA	NA	NA	NA
QA 11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	🔴	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	🔴	NA	NA	NA	NA
QA 12	U	🟢	NA	NA	NA	NA	NA	NA	NA	NA	NA	U	NA	NA	NA	🟢	NA	NA	NA	U	NA	NA	NA	NA	NA	U	NA	NA	🟢	U	NA	U	U

Note: QA = Quality assessment; Symbol of 🟢 = yes; 🔴 = no; 🟣 = partially; (**U**) = unclear and **NA** = not applicable

QA1–QA12 represent the quality assessment criteria adapted from the Joanna Briggs Institute (JBI) critical appraisal checklist. The criteria assess aspects such as study objectives, participant selection, data collection methods, validity and reliability of measurements, management of confounding factors, outcome assessment, and appropriateness of statistical analyses.

4.2.2 Distribution and Scope of Research

Based on the evidence summarised in Table 4.2, several recurring predictors of safety culture were identified, encompassing behavioural, situational, and technological domains such as leadership, training, safety communication, and human–technology interaction (HTI). Geographically, the reviewed studies covered diverse regions including Asia (48.5%), North and South America (21.2%), the Middle East (15.2%), Europe (9.1%), and Africa (6.0%) (Table 4.3). This global distribution mirrors the spatial concentration of oil and gas production activities and highlights the regional variations in regulatory environments, workforce characteristics, and digital readiness. Asian countries particularly Malaysia, Indonesia, and India dominated the research landscape, emphasizing psychosocial hazards, leadership, and communication within technologically advancing production systems. Studies from Europe and North America tended to focus on organisational maturity, digital monitoring systems, and predictive analytics frameworks for process safety. The objectives of these studies primarily clustered into three domains: (i) investigating the components and impacts of safety culture (45.4%); (ii) developing safety frameworks, assessment tools, and maturity models (27.3%); and (iii) exploring interrelationships among behavioural, situational, and technological factors influencing safety culture (27.3%). Together, these foci reveal an increasing convergence between traditional safety science and emerging technological disciplines, underscoring the shift toward digitally augmented safety management.

Table 4.2
Summary of Studies on Safety Culture in the Oil and Gas Industry.

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Masudin et al., (2024)	Indonesia	Investigates the relationship between safety climate (SC), human-technology interaction (HTI), and sustainable development (SD).	IoT significantly influences HTI HTI significantly influences SD SC significantly influences SD: SC moderates the relationship between HTI and SD.	Cross-sectional	Employee perception of safety culture
Rocha et al., (2024)	Brazil	Develops and test a framework for assessing the maturity of safety culture on an oil platform.	The results emphasized that the maturity of safety culture is deeply rooted in everyday practices, not just organisational policies or procedures.	Mixed method	Overall safety performance
Wang et al., (2024)	United States	Examines the current practices of safety culture assessment and worker fatigue management in offshore oil and gas operations.	Current practices include supervisors' observations and workers' self-reports. Resistance to fatigue monitoring due to operational challenges and perceptions that workers should manage fatigue themselves.	Mixed method	Improvement in safety behaviour
Hien et al., (2024)	Vietnam	Examines the influence of safety culture components on workers' safety attitudes, personnel error behaviours, and safety citizenship behaviours	Leadership, psychological safety, safety training, safety management system, personal error behaviour and safety citizenship behaviour significantly influence the safety attitude.	Cross-sectional	Employee perception in safety culture

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Pati S. (2023)	India	Explores the extent to which sustainability reporting can reflect an organisation's safety culture	Stakeholder engagement, materiality assessment, and consistency in reporting specific occupational safety and health metrics were observed.	Cross-sectional	Compliance with safety protocol
Ehiaguina et al., (2024)	Nigeria	Evaluates the safety behaviour and its impact on safety performance among oil and gas workers	Safety participation and safety compliance significantly impact the safety management practices. Work Experience on safety participation: Significant direct impact. Age on Safety Compliance: Significant impact.	Cross-sectional	Improvement in safety behaviour
Parasram et al., (2024)	United States	Analyses severe work-related injuries (amputations, loss of an eye, or inpatient hospitalizations) in the oil and gas extraction (OGE) industry.	Contract workers accounted for the highest proportion of severe injuries, significantly more than drilling contractors, and crude petroleum and natural gas operators.	Cross-sectional	Reduction in Accident rate
Benevides, (2023)	Brazil	Analyses the prevalence and causes of non-occupational medical evacuations among offshore oil and gas workers in	Non-occupational health issues, with the most common causes being gastrointestinal, cardiovascular, and infectious diseases. The study concludes that, due to the increasing importance of safety culture, health issues unrelated to	Retrospective cohort study	Reduction in Accident rate

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
			occupational hazards have become the leading cause of offshore evacuations.		
Payne et al., (2023)	Middle East	Investigates the relationship between general safety climate and process safety climate.	Relationship Between General and Process Safety Climate at the individual level and department level. Process Safety Climate and Process Safety Events show a positive correlation while Process Safety Climate and Unreported Injuries show significant negative relationship.	Cross-sectional	Employee perceptions of safety culture
Ofori et al., (2023)	Ghana	Explores the relationships among safety training, safety knowledge, safety compliance, safety culture, and safety performance.	Safety training significantly influences safety knowledge, safety culture, and safety compliance. Safety Knowledge and safety performance significantly influence Safety Culture:	Cross-sectional	Employee perception of safety culture
McSweeney et al., (2023)	United States	Develops and present a comprehensive multi-component toolkit for assessing safety culture in offshore oil and gas operations.	Safety culture surveys, site inspections, and incident investigation reviews were highlighted as essential components of assessing safety culture. Safety Culture Maturity Model	Mixed method	Overall safety performance

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Kamynina et al., (2023)	Russia	Identifies the level of development of basic competencies in industrial safety among college students being trained to work.	It emphasizes the shared responsibility of administration, teachers, specialists, and students in promoting safety.	Quasi-experimental design	Improvement in safety behaviour
Putri et al., (2023)	Indonesia	Assesses the maturity level of the safety culture.	Proactive commitment, but communication, awareness, and behaviour still needing improvement to achieve higher safety culture maturity.	Cross-sectional	Employee perceptions of safety culture
Liya et al., (2023)	China	Develops a safety management framework specific to the oil and gas pipeline industry.	It outlines seven management layers—essence, method, practice, tool, potential, realization, and cycle to create a holistic and culturally relevant safety management system.	Theoretical	Overall safety performance
Al-Mekhlafi et al., (2022)	Malaysia	Investigates the role of safety culture in the relationship between driver work schedules and driving performance.	Work schedule and safety culture significantly impact driving performance.	Cross-sectional	Improvement of work performance

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Fabiano et al., (2022)	Italy	Investigates the influence of human factors on safety outcomes through identify key areas for safety policy improvement and the development of safety programs.	Significant correlations were found between workers' age and experience and their safety behaviour, attitudes and stress levels.	Cross-sectional	Improvement of safety programs
Mohamad et al., (2022)	Malaysia	Examines the framework of ICC by identifying key factors such as safety culture, supportive environment and management commitment that influence ICC.	Strong safety culture is associated with effective crisis communication ICC significantly influences perceived organisational support, affective commitment, employee crisis perception.	Mixed method	Improvement of communication
Guzman et al., (2022)	Philippines	Investigates five areas: exposure to workplace hazards, workplace policies and procedures, health and safety culture perceptions, self-awareness in safety responsibilities, and COVID-19 preventive measures	Perception of health in the workplace significantly impacts workplace safety.	Cross-sectional	Improvement of safety performance
Kalteh et al., (2022)	Iran	Explores how safety culture influences safety performance, specifically examining whether safety motivation and safety knowledge serve as mediating factors in this relationship.	Safety motivation and safety knowledge can mediate the relationship between safety culture and safety performance.	Cross-sectional	Improvement of safety performance

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Rasmussen & Ahsan (2022)	Denmark	Investigates the program's impact on safety culture by assessing changes in employee attitudes and organisational commitment to safety standard	Safety program led to statistically significant improvements in safety culture metrics.	Mixed method	Improvement of safety programs
Iqbal et al., (2022)	Canada	Establishes a benchmarking framework that integrates the Integrity Management Program (IMP) with Safety Culture Maturity (SCM) using a risk-based approach for oil and gas.	IMP components, including Policy and Commitment, Goals and Objectives, Organisational Roles and Responsibilities, and Training and Competency, demonstrated the highest impact on SCM. Additional IMP components, such as Incident Reporting and Management of Change, were of medium importance.	Mixed method	Benchmarking
Al-Mekhlafi et al., (2023)	Malaysia	Investigates the influence of safety culture on driving performance among oil and gas tanker drivers.	Significant positive effect of safety culture on driving performance.	Cross-sectional	Improvement of work performance
Naji et al., (2021)	Malaysia	Examines the impact of safety culture on safety performance within the oil and gas industry, with a focus on the mediating role of psychosocial hazards.	Psychosocial hazards and safety performance led to statistically significant to safety culture.	Cross-sectional	Improvement of safety performance

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Alomari et al., (2020)	Iraq	Understanding of safety and risk management among engineers in construction sector within the oil and gas industry.	Behaviour-Based Safety (BBS) Knowledge (significant)	Cross-sectional	Risk Management
Nana et al., (2020)	Indonesia	Evaluates the effects of employee factors, management practices, working environment, and safety culture on Occupational Health and Safety (OHS) performance in an oil and gas company in Indonesia.	Employee Factor, management factors & working environment positively significant on OHS performance.	Cross-sectional	Improvement of safety performance
Iqbal et al., (2019)	Canada	Develops a risk-based assessment framework that integrates the Integrity Management Program (IMP) with safety culture assessment to improve safety in the oil and gas pipeline industry.	The results identified four IMP components organisational roles and responsibilities, policy and commitment, risk assessment, and training and competency as significantly impacting safety culture attributes such as leadership, vigilance, empowerment, and resilience.	Mixed method	Risk Management
Al Mazroueiet al., (2019)	Qatar	Examines how factors such as leadership safety behaviours, supervisory safety behaviours, and employee safety training impact employees' perceptions and practices related to safety.	Leadership safety behaviours, supervisory safety behaviours & Safety training transformation of attitudes consistently cited as influential in shaping safety culture.	Case study (Qualitative)	Employee perception

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Quoquab et al., (2018)	Malaysia	Case study is to describe the efforts of organisation in instilling a proactive safety culture within its organisation following an accident that caused significant losses.	Leadership, commitment, communication, behavioural reinforcement, resistant to change.	Case study (Qualitative)	Improvement of safety performance
Ebrahimi et al., (2016)	Iran	Evaluates the effectiveness of administrative interventions on improving health and safety performance.	Impact of toolbox meeting on LTI Training and LTI: more training led to a decrease in LTIs	Quasi-experimental design	Improvement of safety performance
Phusavat et al., (2015)	Thailand	Develops a roadmap for implementing a Safety Culture Maturity Model (SCMM) within enterprises, specifically targeting safety performance improvements.	Effectiveness of Safety Management System; Leadership, and Commitment; Persistent Safety Performance.	Mixed method	Improvement of safety performance
Laplonge, (2014)	Australia	Examines the limitations in safety communication practices within the oil and gas industry, focusing on barriers to effective safety communication and the industry's reliance on compliance-based approaches.	Effective safety communication and negotiating safety practices rather than merely complying with standardised rules.	Theoretical	Improvement of communication
Nair & Siddiqui, (2013)	India	Discusses the use of safety culture assessments as a tool to improve workplace safety.	Commitment, Behaviour, Awareness, Adaptability, Information Sharing, Justness.	Mixed method	Improvement of safety performance

Authors, (year)	Country	Aims	Safety Culture Predictor	Study Design	Research Focus
Chen et al., (2013)	China	Assesses the safety culture using an improved fuzzy comprehensive evaluation model based on the SMART (Specific, Measurable, Attainable, Relevant, Tractable) framework.	Safety materials, behaviours, systems, beliefs, persistence, and openness.	Mixed method	Improvement of safety performance

Note: Key findings from various studies analysing the predictors, aims, study designs, and research focus related to safety culture across different geographical contexts within the oil and gas industry (2013–2024)

4.2.3 Key Predictors and Determinants of Safety Culture

Across studies, several core predictors of safety culture emerged: safety rules (14.8%), safety ownership (10.7%), perception of risk (9.2%), working environment (8.1%), safety communication (7.7%), and safety training (7.4%) (Table 4.3). The integration of human-technology interaction (HTI) indicators such as interface usability, automation trust, and digital competence; further refined the understanding of safety behaviour in increasingly automated work settings. Although behavioural and situational predictors dominated the evidence base, technological readiness, and digital safety governance appeared as emerging yet underexplored dimensions. Only 2.3% of studies explicitly examined technology or equipment availability as determinants of safety outcomes, suggesting a gap in research that bridges engineering innovation with behavioural adaptation. This imbalance reinforces the need for socio-technical frameworks that integrate automation ethics, algorithmic transparency, and digital competency into safety culture models.

Table 4.3
Summary of Key Aspects in Studies on Safety Culture in the Oil and Gas Industry.

Aspects	***n***	**%**
Regions		
▪ Asia	16	48.5
▪ North/ South America	7	21.2
▪ Middle East	5	15.2
▪ Europe	3	9.1
▪ Africa	2	6.0
Key objectives		
▪ Investigating safety culture components and impact	15	45.4
▪ Developing safety framework, tool and maturity models	9	27.3
▪ Exploring relationship between safety factors	9	27.3
Safety culture predictors		
▪ Safety attitude	6	4.6
▪ Peer influence	3	1.2
▪ Safety knowledge	3	4.1
▪ Perception of risks	10	9.2
▪ Management commitment	8	6.2
▪ Safety commitment	7	5.3
▪ Safety ownership	11	10.7
▪ Safety training	6	7.4
▪ Safety communication	9	7.7
▪ Reward recognition	1	0.6
▪ Safety investment	1	0.6
▪ Work competency	5	4.2

▪ Safety rules	16	14.8
▪ Accident/ Incident	7	25.0
▪ Reporting	7	25.0
▪ Working environment	9	32.1
▪ Job satisfaction	3	10.7
▪ Technology equipment	2	7.2
Study design		
▪ Cross sectional studies	16	48.5
▪ Mixed methods	14	42.4
▪ Theoretical or retrospective cohort	3	9.1
Research focus		
▪ Improving safety behaviour and performance	21	63.6
▪ Reducing accident rates	4	12.1
▪ Enhancing employee perception and compliance	8	24.2

Note: The table summarises regional distribution, objectives, safety culture predictors, study designs, and research focus. Regions include Asia, the Americas, the Middle East, Europe, and Africa. Objectives cover investigating safety culture, developing frameworks, and exploring safety factor relationships. Predictors include safety attitudes, management commitment, communication, training, and the work environment. Study designs range from cross-sectional to mixed methods and theoretical approaches, focusing on improving safety behaviour, reducing accidents, and enhancing compliance.

4.2.4 Thematic Categorization of Safety Culture Factors

Thematic synthesis revealed three interdependent themes; behavioural (42.6%), situational (38.3%), and psychological (19.1%) factors each comprising multiple subthemes that collectively describe the complexity of safety culture (Figure 4.1). Behavioural factors were the most dominant, emphasizing communication, training, and leadership engagement as key enablers of safety compliance and proactive behaviour. Effective safety communication (7.7%) was particularly influential in fostering team collaboration and aligning individual behaviours with organisational safety objectives. Safety training (7.4%) and attitudes (4.6%) also contributed substantially, reinforcing that sustained behavioural adaptation requires continual learning and participatory management. Situational factors (38.3%) captured the influence of organisational structures and material resources on safety performance. The prevalence of safety rules (14.8%), favourable working environments (8.1%), and efficient incident management systems (7.1%) underscores the role of institutional design and resource availability in sustaining safety culture. Emerging dimensions such as job satisfaction (1.4%) and technology/equipment availability (2.3%) reflect growing recognition of the importance of ergonomic design and digital system reliability. Psychological factors (19.1%) included risk perception (9.2%), safety knowledge (4.1%), and job satisfaction (1.4%), illustrating how individual cognition and collective trust mediate technological and behavioural outcomes. Studies highlighted that positive risk perception enhances engagement with safety technologies, while low psychological safety may reduce willingness to interact with automated systems.

Collectively, these themes illustrate that behavioural, situational, and psychological factors do not operate in isolation but as part of a dynamic socio-technical system. For instance, risk perception (psychological) directly influences safety communication and training uptake (behavioural), while organisational rules and environmental conditions (situational) enable or constrain behavioural consistency. This integrated framework points toward the necessity of holistic safety governance models that concurrently address human, technological, and environmental variables.

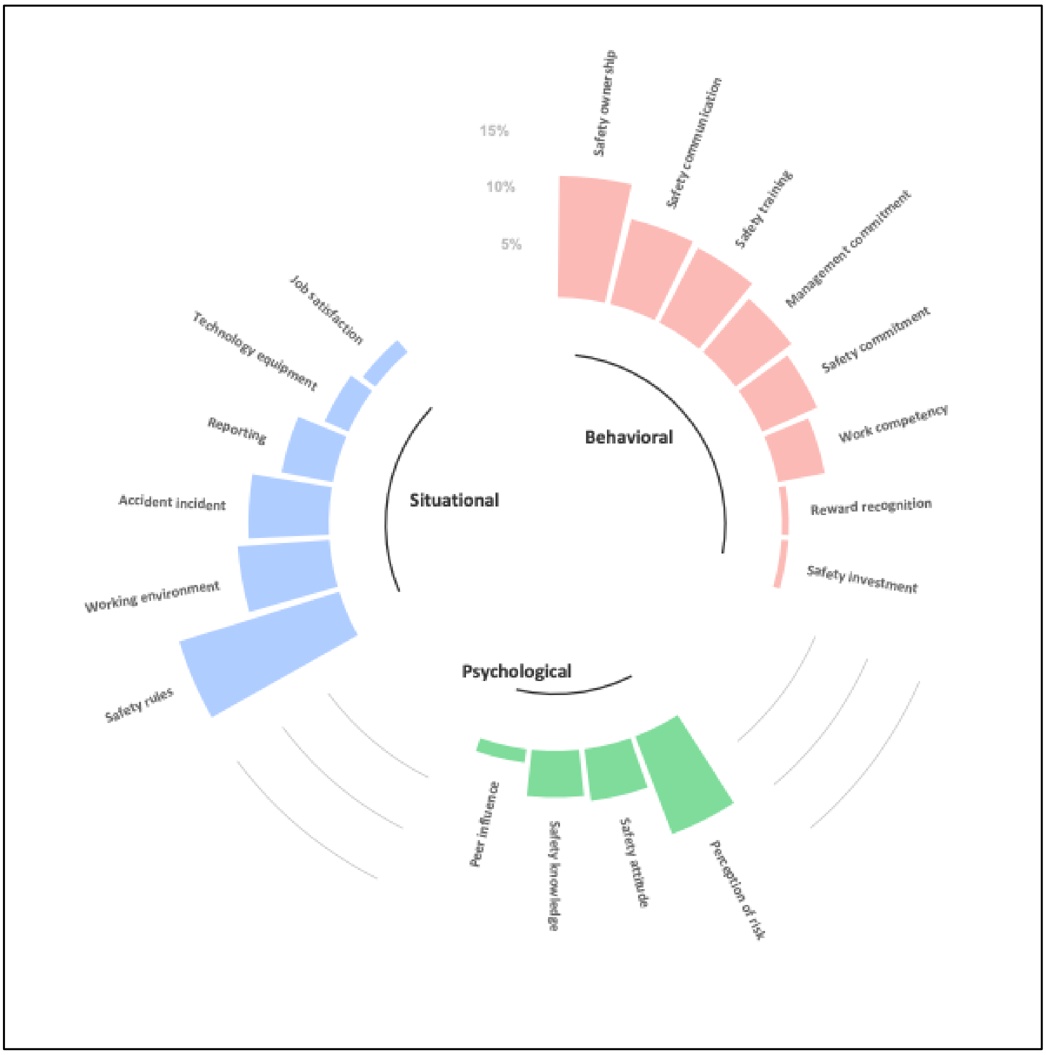

Figure 4.1 Thematic Analysis Revealed Three Primary Themes; Behavioural, Psychological and Situational. Encompassing 18 Sub-Themes That Shape Safety Culture in the Oil and Gas Industry. This Framework Highlights Critical Aspects in Offering a Comprehensive Understanding of the Factors Influencing Safety Practices. Note: The percentages represent the frequency of occurrence of each safety culture element across the reviewed studies relative to the total number of included studies.

4.2.5 Patterns of Association Between Research Focus and Safety Culture Predictors

Hierarchical clustering analysis revealed strong interdependencies between research focus categories and safety culture predictors, as visualized in the clustered heatmap (Figure 4.2). Six primary research foci were identified: *Safety Performance Improvement*, *Employee Perception and Behaviour*, *Organisational Safety Systems and Maturity*, *Risk Management and Benchmarking*, *Communication and Crisis Management*, and *Work Performance and Compliance*.

"*Safety Performance Improvement*" emerged as the most dominant focus, showing strong associations with Behavioural and Psychological Safety (n = 9), Leadership and Management Commitment (n = 8), and Training, Knowledge, and Competency (n = 7). These studies adopted integrated approaches that combined behavioural interventions with digital tracking technologies to enhance safety outcomes. "*Employee Perception and Behaviour*" clustered closely with Training, Knowledge, and Competency (n = 6) and Leadership and Management Commitment (n = 5), indicating sustained interest in workforce-level adaptation and skill enhancement in the face of automation. Meanwhile, "*Organisational Safety Systems and Maturity*" corresponded strongly with Safety Climate and Culture Maturity predictors (n = 7), reflecting an emphasis on digital maturity assessments and data-driven decision tools for safety governance. "*Risk Management and Benchmarking*" studies (n = 5) integrated Integrity Management Programs and process-safety metrics, reflecting how risk intelligence platforms are increasingly used to benchmark safety culture. "*Communication and Crisis Management*" research clustered distinctly with Safety Communication and Integrated Crisis Communication (ICC) predictors (n = 6), underscoring the value of real-time data exchange, social media monitoring, and remote coordination during crises.

Two dominant predictor clusters emerged from dendrogram analysis: one centred on Training, Behavioural Safety, and Leadership, and another linking Risk Management, Communication, and Organisational Maturity. Together, these clusters represent the dual axes of modern safety governance; human adaptability and technological integration that define the transition toward digitally enhanced safety cultures.

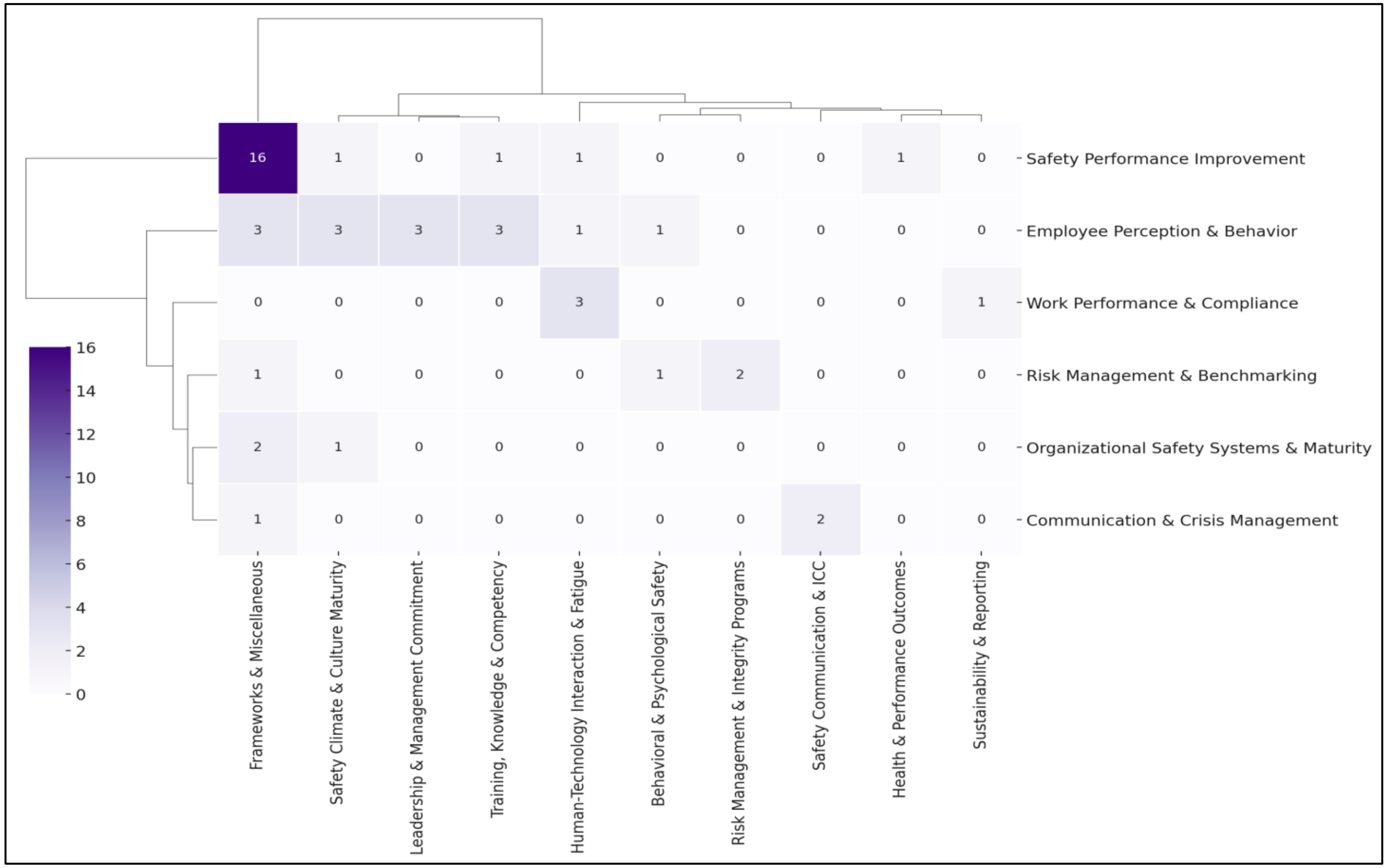

Figure 4.2 Clustered Heatmap with Dendrograms Illustrating the Relationship Between Grouped Research Focus Categories and Safety Culture Predictor Characteristics. Note: Colours indicate the number of studies in each intersection, with deeper purples representing higher frequencies. Hierarchical clustering is applied to both research themes (rows) and predictor characteristics (columns), revealing natural groupings of similar patterns. The colour legend is positioned below left for clarity, and dendrogram lines are emphasized to highlight cluster boundaries. The value "16" represents the number of studies reporting a relationship between safety culture frameworks and safety performance outcomes.

4.2.6 Synthesis and Emerging Research Directions

The synthesis of findings underscores that safety culture within the oil and gas industry is increasingly shaped by the co-evolution of human and technological systems. While behavioural and situational determinants remain central, digital transformation introduces new complexities related to automation trust, algorithmic transparency, and workforce digital literacy. The convergence of AI-assisted monitoring, big-data analytics, and predictive safety modelling offers unprecedented opportunities for proactive risk management but only when paired with strong leadership, ethical governance, and cultural readiness. From a policy perspective, these insights advocate for the establishment of integrated safety governance frameworks that align human-centred design principles with technological innovation. Cross-sectoral lessons from aviation, manufacturing, and renewable energy sectors reveal that adaptive safety culture supported by real-time feedback systems, digital ethics, and participatory training can substantially enhance resilience. Future research should therefore move beyond descriptive studies toward longitudinal, system-oriented analyses that trace how technology adoption transforms collective behaviour and institutional norms across industries.

4.2.7 Discussion

This systematic review examined the psychological, situational, and behavioural determinants of safety culture in the oil and gas industry through the lens of technological transformation and socio-technical adaptation. The findings indicate that safety culture today is shaped not only by human and organisational behaviours but also by the integration of digitalization, automation, and artificial intelligence (AI) in safety management systems. These technologies have enabled predictive analytics, real-time monitoring, and automation of hazard detection, transforming traditional safety approaches into dynamic, data-driven systems. However, their success depends on how effectively organisations align technological solutions with human cognition, regulatory frameworks, and ethical principles. Understanding these interactions is essential to cultivate a proactive, inclusive, and resilient safety culture capable of adapting to digital transitions.

The review underscores how safety culture development is contextually embedded within geographical, cultural, and policy frameworks. Malaysia emerged as a leading contributor to safety-culture scholarship in the oil and gas sector, reflecting national policy commitments such as the Occupational Safety and Health Master Plan 2021–2025 (OSHMP25), which promotes preventive and system-based safety governance (DOSH, 2020). Legislative updates, including the Occupational Safety and Health (Amendment) Act 2022, have institutionalized a culture of accountability and continuous improvement. Malaysia's prominence also stems from its role as one of Southeast Asia's largest petroleum and gas producers and the world's second-largest liquefied natural gas exporter (Iqbal et al., 2019). Together, these developments demonstrate how regulatory leadership and technological investment can create a fertile environment for advancing safety-culture research and practice. Across other regions, similar policy-technology alignments are emerging, particularly where automation, remote sensing, and digital dashboards are incorporated into occupational safety frameworks. This pattern highlights that technological solutions thrive when supported by localized governance structures, cultural adaptation, and participatory engagement from workers and policymakers.

Psychological factors remain fundamental in the digital age, with risk perception and safety attitude identified as the two most influential components. Risk perception shapes how employees interpret hazards and evaluate acceptable levels of exposure, directly influencing adherence to safety protocols (Anwar, 2023). As AI-enabled systems increasingly influence safety decisions, workers must develop trust in algorithmic recommendations and understand their limitations. Studies show that when digital tools are introduced without adequate transparency or training, risk perception can become distorted, leading to over-reliance on automation or scepticism toward its accuracy. Conversely, cultivating safety literacy and participatory design fosters confidence and improves both cognitive and behavioural compliance (Monazam and Soltanzadeh, 2009). Similarly, safety attitude defined as the willingness to internalize safety as a personal and collective responsibility serves as a motivational driver for safe conduct. Positive safety attitudes, when reinforced through technology-mediated feedback and communication, enhance morale and accountability (Merazga et al., 2020 and Wang et al., 2018). Thus, technology does not replace psychological safety; rather, it amplifies its importance by demanding greater trust, adaptability, and ethical awareness among workers.

Situational factors provide the organisational context that shapes behaviour and decision-making. Safety rules and the working environment remain pivotal, but their meaning has evolved. In digitalized operations, safety procedures are increasingly embedded in automated control systems, wearable monitoring devices, and IoT-enabled work platforms. While adherence to standardised protocols remains vital for accident prevention (IOGP, 2022 and Appiah et al., 2021), excessive proceduralizing can paradoxically suppress adaptive judgment (Rocha and Lima, 2018). Organisations now face the challenge of designing flexible, context-aware systems that balance compliance with innovation. Furthermore, environmental conditions ranging from ergonomics to shift scheduling intersect with technological design. Integrating fatigue-detection sensors, digital rest-tracking systems, and adaptive scheduling has proven effective in improving both well-being and performance (Al-Mekhklafi et al., 2023). These findings reaffirm the value of combining technological precision with human-centred design, ensuring that automation supports, rather than constrains, worker agency.

Behavioural elements encompassing safety ownership, communication, and collective accountability bridge individual cognition with institutional systems. The review reveals that safety communication has evolved beyond traditional briefings and memos into a continuous digital dialogue enabled by mobile reporting platforms, learning management systems, and AI-driven analytics dashboards (Al-Rbeawi, 2023 and Al-Arnous, 2022). These tools enhance transparency and empower frontline employees to report hazards in real time, closing the feedback loop between management and workers. Nevertheless, digital divides and linguistic barriers can undermine inclusivity, particularly in multinational operations (Nordin et al.,2021). To address this, organisations should adopt multilingual, accessible communication tools and embed equity principles into their digital safety systems. When combined with leadership engagement and incentives, these approaches foster behavioural alignment and collective ownership of safety outcomes.

The review's synthesis also offers cross-sectoral lessons. The psychological adaptability, situational awareness, and behavioural accountability identified in the oil and gas industry are transferable to other technologically complex domains such as manufacturing, construction, and healthcare. In these sectors, predictive analytics, sensor-based monitoring, and safety-feedback platforms can be adapted to improve situational awareness and compliance. However, the translation of these lessons must remain sensitive to contextual and cultural variations. Imposing oil-and-gas-style protocols on sectors with lower risk or differing workflows may lead to inefficiency or disengagement. The most effective path forward lies in adopting a socio-technical design approach, in which technology, policy, and human behaviour evolve in concert. While the review reveals strong evidence linking digital innovation and safety-culture enhancement, it also exposes several gaps. The predominance of cross-sectional designs limits understanding of how technology reshapes safety behaviour longitudinally. Moreover, few studies address emerging concerns such as algorithmic bias, data privacy, or surveillance fatigue issues that are increasingly relevant as organisations deploy AI-driven safety tools. Future research should incorporate longitudinal and mixed methods designs that capture both behavioural adaptation and technological evolution over time. Combining ethnographic inquiry with machine-learning analytics would allow researchers to map how workers interact with, adapt to, or resist technological safety systems. Policymakers and organisations must also align safety innovation with governance reforms that embed AI ethics, transparency, and participatory accountability within occupational health and safety frameworks.

The evolution of safety culture in the oil and gas industry mirrors the broader societal transformation toward digitally mediated work systems. Psychological, situational, and behavioural factors remain essential, but they now operate within complex data ecosystems that redefine how safety is perceived, enacted, and governed. The challenge is not merely to adopt advanced technologies, but to integrate them within ethical, human-centred, and contextually relevant frameworks. By bridging technological innovation with social understanding and policy responsiveness, the oil and gas sector and industries beyond it can build adaptive, transparent, and resilient safety cultures aligned with sustainable industrial and societal goals.

4.2.8 Conclusion

The research encompassed investigations across the entire oil and gas spectrum. A shift in research trends over the two five-year periods highlighted a maturation of safety culture research, emphasizing complex dynamics and organisational influences. This dynamic evolution underscores the need for continual exploration and adaptation to emerging priorities in organisational safety practices. Three primary themes and 18 sub-themes related to psychological, situational, and behavioural elements was identified. The behavioural element garnered the majority of attention, followed by the situational and psychological elements. Influencing factors such as safety rule adherence, safety ownership, safety communication, and management commitment played pivotal roles, with safety rule and safety ownership standing out as the most impactful. In examining the psychological element, risk perception and safety attitude emerged as crucial factors influencing safety culture. In conclusion, this research provides valuable insights into the multifaceted landscape of safety culture within the oil and gas industry. The influential factors of oil gas can guide future endeavours in enhancing safety practices and promoting a robust safety culture across diverse organisational contexts and may serve a reference for other industries.

4.3 Aim 2: Development and Validation of a Questionnaire on Safety Culture Elements Preference for Oil and Gas Industry [5]

In the high-risk oil and gas industry, where accidents can lead to severe consequences, establishing a robust safety culture is crucial. Safety culture in this context refers to the way in which safety is managed in the workplace, encompassing attitudes, beliefs, perceptions and values shared by employees at all levels (Guldenmund, 2000 and Reason, 2016). Despite the critical importance of safety culture, measuring it accurately and effectively has remained a challenge, particularly due to the diverse operational contexts and geographic regions in which these industries operate (Shirali et al., 2018). Historically, attempts to quantify safety culture have utilised various methodologies, but often without sufficient validation to ensure their effectiveness across different industries and operational settings (Wiegmann et al., 2004). This has led to the development of tools that may not fully capture the nuances of safety culture in specific contexts, particularly in an industry as complex and varied as oil and gas. In response to this, there has been a growing emphasis on the need for a scientifically rigorous approach to developing these assessment tools (Van Nunen et al., 2022 and Pronovost, 2005).

A variety of tools have been developed to assess safety culture, including the Safety Attitudes Questionnaire (SAQ) and the IATA Aviation Safety Culture Survey (IASC), which have been used in sectors such as healthcare and aviation. (Sexton, 2005 and IATA, 2024). The SAQ focuses on measuring attitudes and perceptions related to

[5] Rahim, H., Dapari, R., Dom, N. C., & Mohd Noor, M. I. (2025). Development and Validation of a Questionnaire on Safety Culture Elements Preference for Oil and Gas Industry. *Malaysian Journal of Medicine & Health Sciences*, *21*(5): 178-190.

teamwork, safety climate, and job satisfaction, while the IASC surveys emphasize compliance and organizational safety policies within aviation contexts. However, these tools are often insufficient for the oil and gas industry due to its unique operational complexities and high-risk nature (Rahim et al., 2024). For example, the SAQ lacks situational specificity, making it challenging to address the diverse and hazardous working conditions found in oil and gas environments. Similarly, IASC safety surveys are tailored to International Civil Aviation Organisation (ICAO) and does not account for the distinct safety management practices and cultural diversity inherent to oil and gas operations. Furthermore, many existing tools were designed in culturally homogeneous settings, limiting their adaptability to the workforce characteristic of the oil and gas sector. These limitations highlight the need for a tailored safety culture assessment tool that addresses the specific challenges and operational contexts of the oil and gas industry.

To address these challenges, the current study embarked on the development of a new questionnaire specifically designed for assessing safety culture within the oil and gas sector. This process began with a systematic literature review (SLR), which served to identify and prioritise the key elements of safety culture that are most relevant and critical to the industry. The SLR not only provided a foundational understanding of the existing knowledge base but also highlighted the gaps in current assessment practices, particularly in how they adapt to different cultural and operational environments (Ismail et al., 2021 and Lee et al., 2019). The outcome of this review was instrumental in constructing a questionnaire that is both comprehensive and sensitive to the industry's specific needs. The development process involved multiple stages, including item generation, expert reviews for content validity, and pilot testing to refine the instrument. A rigorous methodology is essential to assess the extent to which an instrument is influenced by measurement error (reliability) and accurately reflects the construct it is designed to measure (validity) (Terwee et al., 2010).

This paper details the rigorous validity process undertaken before the questionnaire's broader distribution, ensuring that the final tool is robust, reliable, and capable of effectively measuring safety culture in diverse settings within the oil and gas industry. The primary objective of this research is not only to introduce a validated tool for safety culture assessment but also to contribute to the broader goal of enhancing safety management practices in the oil and gas industry. By providing a reliable measure of safety culture, the industry can better identify strengths and areas for improvement, leading to targeted interventions that enhance both safety outcomes and operational efficiency.

4.3.1 Face Validity

Based on the feedback from the five respondents, the questionnaire content was clearly understood with no noted ambiguities. The time required to complete the questionnaire ranged from 15 to 20 minutes.

4.3.2 Content Validity Index

The Content Validity Index (CVI) analysis demonstrated acceptable levels of content validity across all constructs following a comprehensive evaluation (16). Dimension-specific insights revealed strong performance in the psychological, situational, and behavioural constructs, as well as the element preference category. Within the psychological construct, all six items achieved CVI scores ranging from 0.86 to 1.00. Items P1, P2, and P3 were collectively rated as highly relevant (CVI = 1.00), reflecting their clarity and alignment with the construct, while items P4, P5, and P6 scored slightly lower (CVI = 0.86). Similarly, the situational construct exhibited strong validity, with all 15 items achieving CVI scores of 0.86 or higher. Twelve items were consistently rated as highly relevant (CVI = 1.00), indicating a high level of agreement on their importance, whereas items S10, S13, and S14 (CVI = 0.86). The behavioural construct showed the variability, with CVI scores ranging from 0.86 to 1.00 across 28 items. While items such as B1, B2, and B3 achieved perfect scores (CVI = 1.00), others, including B5 and B8, scored slightly lower (CVI = 0.86), reflecting the inherent complexity of capturing nuanced safety behaviours. Finally, the element preference category demonstrated unanimous agreement across all items (CVI = 1.00), underscoring the clarity and importance of these elements in assessing safety culture priorities. These results highlight the overall robustness of the instrument, with most items exceeding the threshold for content validity. The findings are detailed in Table 4.4

Table 4.4
Content Validity Index (CVI)

Scale	Items Code (Table 5)	Relevant	Not relevant	CVIs	Interpretation
Psychological	P1	7	0	1.00	Appropriate
	P2	7	0	1.00	Appropriate
	P3	7	0	1.00	Appropriate
	P4	6	1	0.86	Appropriate
	P5	6	1	0.86	Appropriate
	P6	6	1	0.86	Appropriate
Situational	S1	7	0	1.00	Appropriate
	S2	7	0	1.00	Appropriate
	S3	7	0	1.00	Appropriate
	S4	7	0	1.00	Appropriate
	S5	7	0	1.00	Appropriate
	S6	7	0	1.00	Appropriate
	S7	6	0	1.00	Appropriate
	S8	7	0	1.00	Appropriate
	S9	7	0	1.00	Appropriate
	S10	6	1	0.86	Appropriate
	S11	7	0	1.00	Appropriate
	S12	7	0	1.00	Appropriate
	S13	6	1	0.86	Appropriate
	S14	6	1	0.86	Appropriate
	S15	7	0	1.00	Appropriate
Behavioural	B1	7	0	1.00	Appropriate
	B2	7	0	1.00	Appropriate
	B3	7	0	1.00	Appropriate
	B4	7	0	1.00	Appropriate
	B5	6	1	0.86	Appropriate
	B6	7	0	1.00	Appropriate
	B7	7	0	1.00	Appropriate
	B8	6	1	0.86	Appropriate
	B9	6	1	0.86	Appropriate
	B10	7	0	1.00	Appropriate
	B11	6	1	0.86	Appropriate
	B12	6	1	0.86	Appropriate
	B13	6	1	0.86	Appropriate
	B14	6	1	0.86	Appropriate
	B15	6	1	0.86	Appropriate
	B16	6	1	0.86	Appropriate
	B17	6	1	0.86	Appropriate
	B18	6	1	0.86	Appropriate
	B19	6	1	0.86	Appropriate
	B20	6	1	0.86	Appropriate
	B21	7	0	1.00	Appropriate
	B22	7	0	1.00	Appropriate
	B23	6	1	0.86	Appropriate
	B24	6	1	0.86	Appropriate
	B25	6	1	0.86	Appropriate
	B26	6	1	0.86	Appropriate
	B27	6	1	0.86	Appropriate
	B28	6	1	0.86	Appropriate
Significant Safety Culture Element	SE1	7	0	1.00	Appropriate
	SE2	7	0	1.00	Appropriate
	SE3	7	0	1.00	Appropriate

Although several items recorded moderate CVR values, all retained items exceeded the minimum acceptance threshold recommended by Lawshe (1975). These items were retained due to their conceptual relevance and importance in representing the safety culture constructs identified through the systematic literature review and expert consultation process. The retention of these items ensured comprehensive coverage of the psychological, behavioural, and situational dimensions investigated in this study and supported the content validity of the measurement instrument.

The validation panel consisted of experts representing academia, government and regulatory agencies, industry practitioners, and management personnel. The inclusion of multiple stakeholder groups was intended to capture diverse perspectives on safety culture and enhance the comprehensiveness of the prioritisation and validation processes. Although respondents were drawn from different sectors, all participants possessed relevant occupational safety and health knowledge and experience, enabling informed evaluation of the safety culture dimensions and framework proposed in this study. Of the safety and health practitioners involved in the study, the majority possessed professional experience in high-risk sectors, including oil and gas, manufacturing, construction, and government regulatory environments. Although not all practitioners were directly employed within the oil and gas industry at the time of the study, their extensive occupational safety and health experience in high-risk operational settings provided relevant expertise for evaluating the safety culture dimensions and framework proposed in this research.

4.3.3 Content Validation Ratio

The Content Validity Ratio (CVR) analysis confirmed the content validity of the questionnaire, with all items meeting or exceeding the minimum acceptable CVR threshold of 0.50, as recommended for a panel of seven experts. The psychological construct demonstrated strong content validity, with all six items achieving CVR scores between 0.86 and 1.00. Items P1, P2, and P3 achieved unanimous agreement (CVR = 1.00), indicating their high relevance, while items P4, P5, and P6 (CVR = 0.86) also demonstrated strong expert agreement and acceptable content validity. Similarly, the situational construct exhibited high validity, with 12 of the 15 items rated as essential by all experts (CVR = 1.00). However, items S3, S7, S13, and S14 scored slightly lower (CVR = 0.71). The behavioural construct displayed slightly greater variability, with

CVR scores ranging from 0.71 to 1.00 across its 28 items. Several items, such as B1, B2, B3, B6, B7, B21, and B22, achieved perfect scores (CVR = 1.00), reflecting their strong alignment with the construct's objectives. Conversely, items including B11, B16, B20, B23, and B26 (CVR = 0.71) demonstrated acceptable content validity, exceeding the minimum CVR threshold. Lastly, the significant safety culture element construct exhibited unanimous agreement across all three items (SE1, SE2, and SE3), each achieving CVR = 1.00, underscoring their importance in assessing safety culture priorities.

Although some items received moderate expert agreement (CVR = 0.71), they were retained in the questionnaire due to their conceptual relevance and practical significance in capturing the dimensions of safety culture. Additionally, these items were not deemed problematic by the expert panel, and no recommendations were made for their removal or modification. To ensure clarity and contextual alignment, future studies may consider further refinement or rewording of these items based on larger-scale pilot testing and factor analysis. Overall, the CVR analysis validated the questionnaire's robustness in addressing key dimensions of safety culture while identifying specific items for further refinement to enhance clarity and contextual alignment. The CVR results are presented in Table 4.5.

Table 4.5
Content Validation Ratio

Scale	**Items Code (Table 5)**	**Essential SME**	**Not Essential SME**	**CVRs**	**Interpretation**
Psychological	P1	7	0	1.00	Appropriate
	P2	7	0	1.00	Appropriate
	P3	7	0	1.00	Appropriate
	P4	6	1	0.86	Appropriate
	P5	6	1	0.86	Appropriate
	P6	6	1	0.86	Appropriate
Situational	S1	7	0	1.00	Appropriate
	S2	7	0	1.00	Appropriate
	S3	5	2	0.71	Appropriate
	S4	6	1	0.86	Appropriate
	S5	6	1	0.86	Appropriate
	S6	7	1	0.86	Appropriate
	S7	5	2	0.71	Appropriate
	S8	7	0	1.00	Appropriate
	S9	6	1	0.86	Appropriate
	S10	6	1	0.86	Appropriate
	S11	7	0	1.00	Appropriate
	S12	7	0	1.00	Appropriate
	S13	5	2	0.71	Appropriate

Scale	Items Code (Table 5)	Essential SME	Not Essential SME	CVRs	Interpretation
	S14	5	2	0.71	Appropriate
	S15	6	1	0.86	Appropriate
Behavioural	B1	7	0	1.00	Appropriate
	B2	7	0	1.00	Appropriate
	B3	7	0	1.00	Appropriate
	B4	6	1	0.86	Appropriate
	B5	6	1	0.86	Appropriate
	B6	7	0	1.00	Appropriate
	B7	7	0	1.00	Appropriate
	B8	6	1	0.86	Appropriate
	B9	6	1	0.86	Appropriate
	B10	6	1	0.86	Appropriate
	B11	5	2	0.71	Appropriate
	B12	6	1	0.86	Appropriate
	B13	6	1	0.86	Appropriate
	B14	6	1	0.86	Appropriate
	B15	6	1	0.86	Appropriate
	B16	5	2	0.71	Appropriate
	B17	6	1	0.86	Appropriate
	B18	6	1	0.86	Appropriate
	B19	6	1	0.86	Appropriate
	B20	5	2	0.71	Appropriate
	B21	7	0	1.00	Appropriate
	B22	7	0	1.00	Appropriate
	B23	5	2	0.71	Appropriate
	B24	6	1	0.86	Appropriate
	B25	6	1	0.86	Appropriate
	B26	5	2	0.71	Appropriate
	B27	6	1	0.86	Appropriate
	B28	6	1	0.86	Appropriate
Significant Safety Culture Element	SE1	7	0	1.00	Appropriate
	SE2	7	0	1.00	Appropriate
	SE3	7	0	1.00	Appropriate

The Content Validity Ratio (CVR) measures the degree to which experts consider an item essential, whereas the Content Validity Index (CVI) evaluates the relevance, clarity, and representativeness of the items. CVR is calculated based on the proportion of experts rating an item as essential, while CVI is derived from expert ratings on item relevance and content adequacy.

4.3.4 Reliability Questionnaire

The questionnaire item based on items code are shown in Table 4.6. The Cronbach's alpha values for the Safety Culture Questionnaire (SCQ) are shown in Table 4.7. The result indicates strong internal consistency across all dimensions. Each dimension's alpha value surpasses the 0.7 threshold, demonstrating the questionnaire's reliability. These results affirm that the SCQ is a reliable instrument for evaluating safety culture in diverse contexts within the oil and gas industry. While high Cronbach's alpha values (>0.90) suggest strong internal consistency, they may also indicate potential redundancy in questionnaire items. The behavioural dimension, in particular, recorded an alpha value of 0.982, which is notably high. However, upon reviewing the item pool, no immediate redundancies were identified, as each item captured distinct yet related aspects of behavioural safety culture. Given the comprehensive nature of the behavioural construct, which encompasses various sub-elements, high inter-item correlations were expected. Although no items were removed in this study, future refinements could involve exploratory factor analysis (EFA) to assess whether specific items can be consolidated or revised to reduce redundancy while maintaining conceptual integrity. Additionally, item-total correlations could be further analysed to determine if any items contribute minimally to construct variance. These refinements will help streamline the SCQ for more efficient application in future studies.

Table 4.6
Items Code of Questionnaire

Scale	Items Code	Items
Psychological	P1	How much more important is 'Safety Attitude' than 'Safety Influence' in its effects on Psychological?
	P2	How much more important is 'Safety Attitude' than 'Safety Knowledge' in its effects on Psychological?
	P3	How much more important is 'Safety Attitude' than 'Perception of Risk' in its effects on Psychological?
	P4	How much more important is 'Safety Influence' than 'Safety Knowledge' in its effects on Psychological?
	P5	How much more important is 'Safety Influence' than 'Perception of Risk' in its effects on Psychological?
	P6	How much more important is 'Safety Knowledge' than 'Perception of Risk' in its effects on Psychological?
Situational	S1	How much more important is 'Safety Rule' than 'Safe Reporting' in its effects on Situational?
	S2	How much more important is 'Safety Rule' than 'Working Environment' in its effects on Situational?
	S3	How much more important is 'Safety Rule' than 'Job Satisfaction' in its effects on Situational?
	S4	How much more important is 'Safety Rule' than 'Technology Equipment' in its effects on Situational?
	S5	How much more important is 'Safety Rule' than 'Accident Incident' in its effects on Situational?

Scale	Items Code	Items
	S6	How much more important is ‘Safety Reporting’ than ‘Working Environment’ in its effects on Situational?
	S7	How much more important is ‘Safety Reporting’ than ‘Job Satisfaction’ in its effects on Situational?
	S8	How much more important is ‘Safety Reporting’ than ‘Technology Equipment’ in its effects on Situational?
	S9	How much more important is ‘Safety Reporting’ than ‘Accident and Incident’ in its effects on Situational?
	S10	How much more important is ‘Working Environment’ than ‘Job Satisfaction’ in its effects on Situational?
	S11	How much more important is ‘Working Environment’ than ‘Technology Equipment’ in its effects on Situational?
	S12	How much more important is ‘Working Environment’ than ‘Accident Incident’ in its effects on Situational?
	S13	How much more important is ‘Job Satisfaction’ than ‘Technology Equipment’ in its effects on Situational?
	S14	How much more important is ‘Job Satisfaction’ than ‘Accident Incident’ in its effects on Situational?
	S15	How much more important is ‘Technology Equipment’ than ‘Accident Incident’ in its effects on Situational?
Behavioural	B1	How much more important is ‘Management Commitment’ than ‘Safety Ownership’ in its effects on Behavioural?
	B2	How much more important is ‘Management Commitment’ than ‘Safety Training’ in its effects on Behavioural?
	B3	How much more important is ‘Management Commitment’ than ‘Safety Communication’ in its effects on Behavioural?
	B4	How much more important is ‘Management Commitment’ than ‘Reward Recognition’ in its effects on Behavioural?
	B5	How much more important is ‘Management Commitment’ than ‘Safety Investment’ in its effects on Behavioural?
	B6	How much more important is ‘Management Commitment’ than ‘Safety Competency’ in its effects on Behavioural?
	B7	How much more important is ‘Management Commitment’ than ‘Safety Commitment’ in its effects on Behavioural?
	B8	How much more important is ‘Safety Ownership’ than ‘Safety Training’ in its effects on Behavioural?
	B9	How much more important is ‘Safety Ownership’ than ‘Safety Communication’ in its effects on Behavioural?
	B10	How much more important is ‘Safety Ownership’ than ‘Reward Recognition’ in its effects on Behavioural?
	B11	How much more important is ‘Safety Ownership’ than ‘Safety Investment’ in its effects on Behavioural?

Scale	Items Code	Items
	B12	How much more important is ‘Safety Ownership’ than ‘Safety Competency’ in its effects on Behavioural?
	B13	How much more important is ‘Safety Ownership’ than ‘Safety Commitment’ in its effects on Behavioural?
	B14	How much more important is ‘Safety Training’ than ‘Safety Communication’ in its effects on Behavioural?
	B15	How much more important is ‘Safety Training’ than ‘Reward Recognition’ in its effects on Behavioural?
	B16	How much more important is ‘Safety Training’ than ‘Safety Investment’ in its effects on Behavioural?
	B17	How much more important is ‘Safety Training’ than ‘Safety Competency’ in its effects on Behavioural?
	B18	How much more important is ‘Safety Training’ than ‘Safety Commitment’ in its effects on Behavioural?
	B19	How much more important is ‘Safety Communication’ than ‘Reward Recognition’ in its effects on Behavioural?
	B20	How much more important is ‘Safety Communication’ than ‘Safety Investment’ in its effects on Behavioural?
	B21	How much more important is ‘Safety Communication’ than ‘Safety Competency’ in its effects on Behavioural?
	B22	How much more important is ‘Safety Communication’ than ‘Safety Commitment’ in its effects on Behavioural?
	B23	How much more important is ‘Reward Recognition’ than ‘Safety Investment’ in its effects on Behavioural?
	B24	How much more important is ‘Reward Recognition’ than ‘Safety Competency’ in its effects on Behavioural?
	B25	How much more important is ‘Reward Recognition’ than ‘Safety Commitment’ in its effects on Behavioural?
	B26	How much more important is ‘Safety Investment’ than ‘Safety Competency’ in its effects on Behavioural?
	B27	How much more important is ‘Safety Investment’ than ‘Safety Commitment’ in its effects on Behavioural?
	B28	How much more important is ‘Safety Competency’ than ‘Safety Commitment’ in its effects on Behavioural?
Significant Of Safety Culture Elements	SE1	How much more important is ‘Psychological’ than ‘Situational’ in its effects on Safety Culture?
	SE2	How much more important is ‘Psychological’ than ‘Behavioural’ in its effects on Safety Culture?
	SE3	How much more important is ‘Behavioural’ than ‘Situational’ in its effects on Safety Culture?

Table 4.7
Cronbach's Alpha of the Safety Culture Questionnaire (SCQ)

	Before deletion and modification	
	Cronbach's alpha	Items
Psychological	0.926	6
Situational	0.923	15
Behavioural	0.982	28
Significant Element Safety Culture	0.912	3
Total items		**52**

4.3.5 Discussion

The CVI results demonstrate that all 52 items of the Safety Culture Questionnaire (SCQ) exhibit high relevance and appropriateness, with CVI values ranging from 0.86 to 1.00 across the psychological, situational, behavioural, and preference safety culture elements dimensions. These findings indicate strong content validity, as each item was deemed appropriate by the expert panel. Notably, items within the psychological and situational categories showed consistent appropriateness, reflecting the robust design of the questionnaire. The particularly high CVI values in the behavioural category underscore the importance of behavioural factors in fostering a proactive safety culture, as they directly influence employee behaviours and attitudes towards safety (Zou, 2011, Asamani, 2020 and Hien et al., 2024). The comprehensive consideration of these factors in the SCQ reflects a thorough understanding of what constitutes a strong safety culture, especially in high-risk sectors like oil and gas. The CVR results further validate the essentiality of the SCQ items, with CVR values consistently meeting or exceeding the minimum threshold of 0.71. This indicates a high level of agreement among the expert panel regarding the necessity of these items. The psychological dimension again shows strong support, with all items achieving a CVR of 1.00, reaffirming their critical role in assessing safety culture. Similarly, the situational and behavioural dimensions also performed well, underscoring the importance of these elements in capturing the multifaceted nature of safety culture (Bisbey et al., 2021, Cooper, 2000 and Guldenmund, 2000). The consistency in high CVR values across dimensions suggests that the SCQ is well-grounded in both theoretical and practical aspects, making it a reliable tool for measuring safety culture in complex environments like the oil and gas sector.

The reliability analysis, measured by Cronbach's Alpha, indicates excellent internal consistency for the SCQ across all dimensions. The psychological dimension achieved a Cronbach's Alpha of 0.926, the situational dimension 0.923, and the behavioural dimension 0.982, all of which exceed the widely accepted threshold of 0.7, demonstrating that the questionnaire items consistently measure the underlying constructs. The preference safety culture elements dimension also showed strong reliability with a Cronbach's Alpha of 0.912. These results not only validate the robustness of the SCQ but also emphasize its potential as a dependable instrument for ongoing safety culture assessments. These findings align with recent literature that underscores the importance of high internal consistency in safety culture assessments to ensure that interventions are based on reliable data (Choudhry et al., 2007, Singla et al., 2006 and Frazier et al., 2013).

When compared to existing safety culture assessment tools such as the Safety Attitudes Questionnaire (SAQ) and the Integrated Aviation Safety Culture (IASC) model, the SCQ differentiates itself by incorporating behavioural, situational, and psychological dimensions tailored specifically to the oil and gas industry. Unlike generic safety climate tools, the SCQ is structured to align with industry-specific risks, regulatory frameworks, and operational challenges, making it a more practical and targeted assessment tool for companies operating in high-risk environments. The SCQ also integrates the Analytic Hierarchy Process (AHP), allowing organisations to prioritise safety culture elements based on their specific operational needs. This feature enhances decision-making for targeted safety interventions; a capability not commonly found in traditional safety culture assessment instruments. The SCQ's high reliability and content validity make it a valuable tool for organisations aiming to enhance safety performance in high-risk industries. To maximize its application, companies can implement the SCQ for safety audits, compliance assessments, and risk management. For safety audits, the SCQ can serve as an internal benchmarking tool to track safety culture performance across departments or sites. In compliance assessments, organisations can use the SCQ to evaluate adherence to industry standards and identify areas for regulatory improvement. Regarding risk management, the SCQ results can inform proactive safety interventions by identifying behavioural gaps that contribute to workplace hazards.

The validated Safety Culture Questionnaire (SCQ) offers significant potential for practical application in organisational settings, particularly in identifying safety culture gaps and guiding targeted interventions. Organisations can use the SCQ to assess psychological, situational, and behavioural dimensions of safety culture, enabling them to pinpoint strengths and weaknesses. By analysing SCQ results, companies can develop data-driven interventions, such as leadership engagement programs, enhanced safety communication strategies, and targeted training initiatives to address identified deficiencies. Future studies should focus on larger-scale validation across multiple oil and gas companies to confirm the SCQ's reliability and applicability in different operational environments. Additionally, cross-cultural validation in industries such as aviation, construction, and healthcare could provide insights into the SCQ's adaptability across high-risk sectors. These extensions would strengthen the generalisability of the SCQ and enhance its potential as a standard safety culture assessment tool. Furthermore, longitudinal studies should be conducted to assess how SCQ scores evolve over time and whether interventions based on SCQ insights lead to measurable improvements in workplace safety. Establishing a benchmarking database using SCQ results across organisations would allow companies to compare safety culture performance against industry standards, fostering a culture of continuous improvement. For instance, organisations with high safety culture scores could serve as role models, sharing best practices with industry peers. Additionally, given the global nature of the oil and gas industry, future research should explore how organisational and cultural differences influence safety culture perceptions, ensuring that the SCQ remains relevant and adaptable for multinational organisations.

This study employed a rigorous validation process, incorporating Content Validity Index (CVI), Content Validity Ratio (CVR), and Cronbach's Alpha analysis, which ensured the questionnaire's robustness and reliability. The involvement of a diverse panel of experts from academia and the oil and gas industry contributed to the high content validity of the questionnaire, making it well-suited for practical application. The Cronbach's Alpha values across all domains indicate excellent internal consistency, reinforcing the questionnaire's reliability as a tool for assessing safety culture. The SCQ was specifically designed for the oil and gas industry, addressing the unique challenges and safety culture aspects relevant to this high-risk sector.

However, certain limitations should be acknowledged. While the study included a robust expert panel, the sample size may limit generalisability, necessitating larger-scale validation studies in diverse industry settings. The SCQ was designed and validated within the oil and gas sector, which may impact its applicability to other industries with different safety culture dynamics. Additionally, this study did not include a longitudinal assessment, which could provide insights into the SCQ's long-term reliability and effectiveness in tracking safety culture improvements over time. Future research should address these limitations by conducting multi-industry validations and longitudinal assessments.

4.3.6 Conclusion

The validated safety culture questionnaire represents a significant tool for future research, offering the potential to systematically identify and address critical elements of safety culture preferences. By facilitating targeted interventions, it stands to contribute meaningfully to the enhancement of occupational safety and health culture practices within organizations.

4.4 Aim 3: Decoding Stakeholder Priorities of Safety Culture Preferences in the Oil and Gas Industry [6]

Safety culture in the oil and gas industry is paramount to ensure operational safety as well as to safeguard human lives and the environment (Sugiono et al., 2020, Almazrouei et al., 2020 and Glebova et al., 2023) Safety culture refers to the shared attitudes, beliefs, perceptions, and values that employees hold regarding safety within an organisation (Uttal, 1983, Guldenmund, 2000 and Reason, 2016). It encompasses the commitment to safety at all levels of the organisation, influencing behaviour and decision-making processes aimed at preventing accidents and promoting a safe working environment (Goncalves and Waterson, 2018). Comprehensive integration of safety culture into the workplace environment is crucial as it forms one of the cornerstones of the holistic health, safety and environment culture (Emetumah, 2016). Without a comprehensive safety culture, the repercussions can be profound, directly causing accidents and injuries among oil and gas workers. Hence, robust accident prevention

[6] Rahim, H., Dapari, R., Che Dom, N., & Mohd Noor, M. I. (2024). Decoding Stakeholder Priorities of Safety Culture Preferences in the Oil and Gas Industry. *Scientific Reports*, *14*(1), 20735.

measures are vital in this sector (Ehiaguina et al., 2024, Gao et al., 2019 and Iqbal et al., 2019).

In Malaysia, the oil and gas sector is a major contributor to the nation's economy (Zakaria et al., 2023). As one of the largest contributors to the nation's GDP, the oil and gas sector significantly impacts Malaysia's economic stability and growth (Kriskkumar et al., 2022). However, it is also associated with inherent risks stemming from suboptimal safety management practices (Wanasinghe et al., 2020, Naevestad et al., 2019 and Tang, 2021). Diverse regulatory practices, cultural influences on safety perceptions, and varied organisational safety practices further complicate the establishment of a unified safety culture across the industry (Ajmal et al., 2022 and Almutairi, 2019). Moreover, the safety landscape is highly dynamic as shaped by continuous technological advancements and evolving regulatory frameworks. Hence, an adaptable and responsive approach to safety culture development plays an important role in this industry (Ismail et al., 2023 and Roberts et al., 2021). In Malaysia, the oil and gas industry has been the subject of numerous studies, focusing on various aspects such as operational efficiency, environmental impact, and safety management practices (Rahim et al., 2023). Earlier studies have highlighted several major concerns regarding safety in the industry, including leadership, lack of effective communication, and insufficient safety training (Ajmal et al., 2022 and Rashid et al., 2023) These issues have been identified as contributing factors to workplace accidents, which can have devastating consequences in terms of both human life and economic loss. As the industry continues to evolve with technological advancements and shifting regulatory frameworks, these safety concerns remain pertinent, requiring ongoing attention and improvement.

The development of a robust safety culture within the oil and gas industry is a critical component of organisational success, particularly in high-risk environments where the stakes are exceedingly high. Central to this endeavour is the understanding and integration of stakeholder preferences, which play a pivotal role in shaping safety practices that are both effective and sustainable. Sustainability initiatives, as highlighted in recent reviews of the petroleum industry, underscore the need for industry-specific strategies that align with environmental and social priorities, further emphasizing the importance of tailoring safety culture practices to local contexts (Bathrinath et al., 2021). Drawing on the principles of stakeholder theory, it is evident that aligning safety culture initiatives with the interests and expectations of key stakeholders such as employees, management, and regulators is essential for ensuring their successful implementation and long-term viability. Similarly, the role of ergonomic factors in industries such as leather garment manufacturing highlights the importance of considering worker well-being and social sustainability in the development of safety practices, pointing to the broader implications of safety culture beyond mere compliance (Karuppiah et al., 2020). However, existing research often fails to account for the nuanced preferences of local stakeholders, leading to potential misalignments between global safety norms and the specific cultural, economic, and regulatory contexts in which these practices are deployed. This gap underscores the necessity of a tailored approach to safety culture development, one that is informed by the unique characteristics of the local environment. By embedding stakeholder theory into the foundation of safety culture strategies, organisations within the oil and gas sector can create more resonant and contextually appropriate safety practices, thereby enhancing overall safety performance and organisational resilience.

The components of safety culture chosen for this study were carefully selected based on a thorough review of existing literature and their demonstrated significance in the context of the oil and gas industry. The decision to focus on specific elements such as management commitment, safety communication, safety training, and safety ownership; was influenced by their recurrent identification as foundational elements of an effective safety culture in the literature. For instance, Reason (2016) emphasizes management commitment as a cornerstone of safety culture, highlighting that leadership plays a crucial role in establishing and maintaining safety norms within an organisation. Similarly, Guldenmund (2000) identifies safety communication as essential for fostering a transparent and informed safety environment, where workers are encouraged to voice concerns and share safety-related information freely (Reason, 2016). Furthermore, Hopkins (2006) underscores the importance of safety training and competency in ensuring that workers are adequately prepared to handle the complexities and hazards of the oil and gas industry (Hopkins, 2006). Safety ownership is another critical element, as described by Cooper (2000), which involves employees taking personal responsibility for safety and proactively contributing to a safer workplace (Cooper, 2000). By comprehensively understanding stakeholder preferences, organisations can develop targeted safety culture strategies that resonate with the diverse needs of stakeholders. Besides enhancing safety outcomes, it will also foster greater engagement and buy-in from those involved in the implementation process.

Therefore, bridging the gap between overarching safety culture frameworks and localised stakeholder preferences is essential for cultivating a robust safety culture within the oil and gas industry.

The Analytic Hierarchy Process (AHP) is a powerful decision-making tool that has not been widely applied in the context of safety culture, especially within the Malaysian oil and gas sector. AHP was chosen for this study due to its ability to systematically decompose complex decisions into a hierarchy of more manageable sub-problems, each of which can be analysed independently (Saaty, 2008 and Mu et al., 2016). This makes AHP particularly suitable for prioritising elements of safety culture, where multiple criteria need to be evaluated based on the preferences of diverse stakeholders. The AHP method has been successfully used in other high-risk industries, such as construction and manufacturing, demonstrating its applicability and effectiveness in contexts similar to the oil and gas industry (Darko et al., 2019 and Jamwal et al., 2021). Moreover, AHP method has been widely applied in international context in safety management (Lim et al., 2021 and Unver 2021). One of the key advantages of AHP is its ability to incorporate both quantitative and qualitative data, allowing for a comprehensive evaluation of stakeholder preferences. Additionally, AHP facilitates consensus-building among stakeholders by providing a clear, transparent framework for decision-making, which is crucial for ensuring the successful implementation of safety culture initiatives. This structured methodology provides a systematic approach for organising and analysing complex decisions, as well as offering quantifiable insights into stakeholders' priorities. By leveraging the AHP method, researchers can gain a clearer understanding of the elements deemed most crucial by stakeholders directly impacted by safety culture decisions. By identifying and understanding the stakeholder preferences and priorities in the Malaysian oil and gas industry, more tailored and effective safety culture strategies can be developed to fulfil the specific needs and expectations of stakeholders. This targeted approach enhances the likelihood of successful implementation and acceptance of safety initiatives among the end users.

The oil and gas industry in Malaysia, a critical contributor to the national economy, faces significant challenges in establishing a unified safety culture due to diverse regulatory practices, cultural influences, and varied organisational safety protocols (Ajmal et al., 2022 and Waqar et al., 2024). Despite the importance of safety culture in preventing accidents and safeguarding human lives, existing research often overlooks the nuanced preferences and priorities of local stakeholders, which are shaped by specific cultural, economic, and regulatory contexts (Grote, 2007 and Hudson, 2007). This gap in the literature raises concerns about the effectiveness of general safety culture initiatives that fail to resonate with the local workforce and other key stakeholders. To address this issue, this study seeks to answer the research question: "What are the key elements of safety culture as perceived by various stakeholders in the Malaysian oil and gas sector, and how can these elements be prioritised to develop more tailored and effective safety strategies?" Therefore, this study aimed to identify and prioritise key elements of safety culture as perceived by various stakeholders in the Malaysian oil and gas sector. By establishing a safety culture framework grounded in evidence from a systematic literature review, the study delineated crucial factors for fostering a comprehensive HSE culture. Prioritising these elements facilitates the strategic allocation of resources and efforts towards areas with the greatest potential for impact, thereby maximizing safety performance in the oil and gas sector. Additionally, the study employed the Analytic Hierarchy Process (AHP) methodology to integrate stakeholder perspectives into the decision-making process, ensuring that the safety culture established within organisations is both effective and resonates with the diverse needs of all those involved in or affected by oil and gas industry operations in Malaysia.

However, it is important to acknowledge the limitations of this study. The non-randomness of the sample limits the generalisability of the findings, and the participation of respondents from four different groups, while providing diverse perspectives, also presents certain drawbacks. These include potential biases in how different groups perceive safety culture, which may influence the prioritisation of safety elements. These limitations should be considered when interpreting the results and applying them to broader contexts. Despite these limitations, this study makes several original contributions to science, practice, and society. Scientifically, it advances the understanding of safety culture within the oil and gas sector by identifying and prioritising key elements based on stakeholder preferences, a relatively underexplored area in existing literature. Practically, the study provides a framework that organisations can use to tailor their safety culture initiatives to better align with the specific needs of their workforce, enhancing the effectiveness of safety programs. Societally, by promoting a stronger safety culture, the study contributes to reducing the risk of accidents and improving the overall well-being of workers in the Malaysian oil and gas industry, with potential implications for similar industries globally.

4.4.1 Characteristics of Study Participants

The characteristics of study participants are shown in Table 4.8. The study participants were predominantly male (n = 70%) with an average age of 38 years. They exhibited a diverse educational background, with most of them holding a Bachelor's Degree (n = 47.5%), followed by a Master's Degree (n = 27.5%) or Ph.D. (n = 10%), while the rest possessed diplomas or professional certificates. There was an equal distribution between those employed by government/statutory bodies (n = 55.0%) and those in private or multinational companies (n = 45.0%). Their professional roles varied, including Safety & Health Practitioners (n = 40%), Government/Regulator Officers (n = 35%), and others in academic or managerial positions. The majority (n = 92.5%) of them were actively involved in OSH.

Table 4.8
Characteristics of Study Participants

Characteristic	***n* = 40 (%)**
Age (Average year)	38 (SD = 7.5)
Gender	
Male	28 (70.0)
Female	12 (30.0)
Education Background	
Ph.D.	4 (10.0)
Master's Degree	11 (27.5)
Bachelor's Degree	19 (47.5)
Diploma	3 (7.5)
Professional Certificate	3 (7.5)
Type of Organisation	
Government/Statutory Body	22 (55.0)
Private/Multinational/GLC	18 (45.0)
Sector	
Oil and gas	7 (17.5)
Education	6 (15.0)
Government & Regulatory Body	19 (47.5)
Other Industries	8 (20.0)

Characteristic	*n* = 40 (%)
Stakeholder	
Safety & Health Practitioner	16 (40.0)
Government//Regulator Officer	14 (35.0)
Lecturer/Researcher/Trainer	5 (12.5)
Management/Manager	5 (12.5)

Note: The demographic profile summarised above reflects the characteristics of the 40 stakeholders who participated in the study. Percentages are based on the total sample size (n = 40). Age is reported as mean ± standard deviation. Participants were drawn from multiple organisational sectors and job roles to ensure broad representation of perspectives on safety culture within the oil and gas industry. Percentages may not total 100% within categories due to rounding.

The respondent composition should be considered when interpreting the prioritisation results. Although only seven respondents were directly from the oil and gas industry, all expert participants possessed relevant occupational safety and health expertise, particularly in high-risk industries such as oil and gas, manufacturing, construction, and regulatory environments. The inclusion of diverse stakeholder groups was intended to obtain broader perspectives on safety culture dimensions and strengthen the comprehensiveness of the prioritisation process. Nevertheless, future studies may consider increasing the proportion of oil and gas practitioners to further strengthen the industry-specific applicability of the findings.

Although respondents from the oil and gas industry represented a smaller proportion of the expert panel, participants from government agencies, regulatory bodies, academia, and other industries possessed extensive occupational safety and health expertise relevant to high-risk industries. Their inclusion was considered beneficial in obtaining a broader perspective on safety culture dimensions and strengthening the robustness of the prioritisation process. Nevertheless, the findings should be interpreted within this context, and future studies may consider increasing the proportion of oil and gas practitioners to further strengthen the industry-specific applicability of the framework.

4.4.2 Stakeholder Preferences

Figure 4.3 represents a detailed matrix of how different professions perceived various safety culture criteria in this study. Each cell in the matrix represents the percentage of respondents who prioritised different aspects of safety, such as attitudes, knowledge, rules, management commitment, ownership, training, and communication. The colour gradient from white to dark purple illustrated an increasing level of response.

Safety & Health Practitioners tended to focus more on practical safety rules and management commitment. Academicians appeared to emphasise more on theoretical aspects of safety, such as knowledge and training. Management personnel showed a broader range of focus, from emphasising practical approaches to safety ownership and communication. Policy makers showed lower responses across various categories, which might suggest that they hold a broader, more policy-oriented perspective on safety culture rather than prioritising specific measures. To understand these preferences better, the demographic compositions of the participants, including age, gender, professional experience, geographical location, and industry, must be further analysed to explain the biases in responses and more importantly, to determine how these preferences can be translated into actual safety practices within their respective fields.

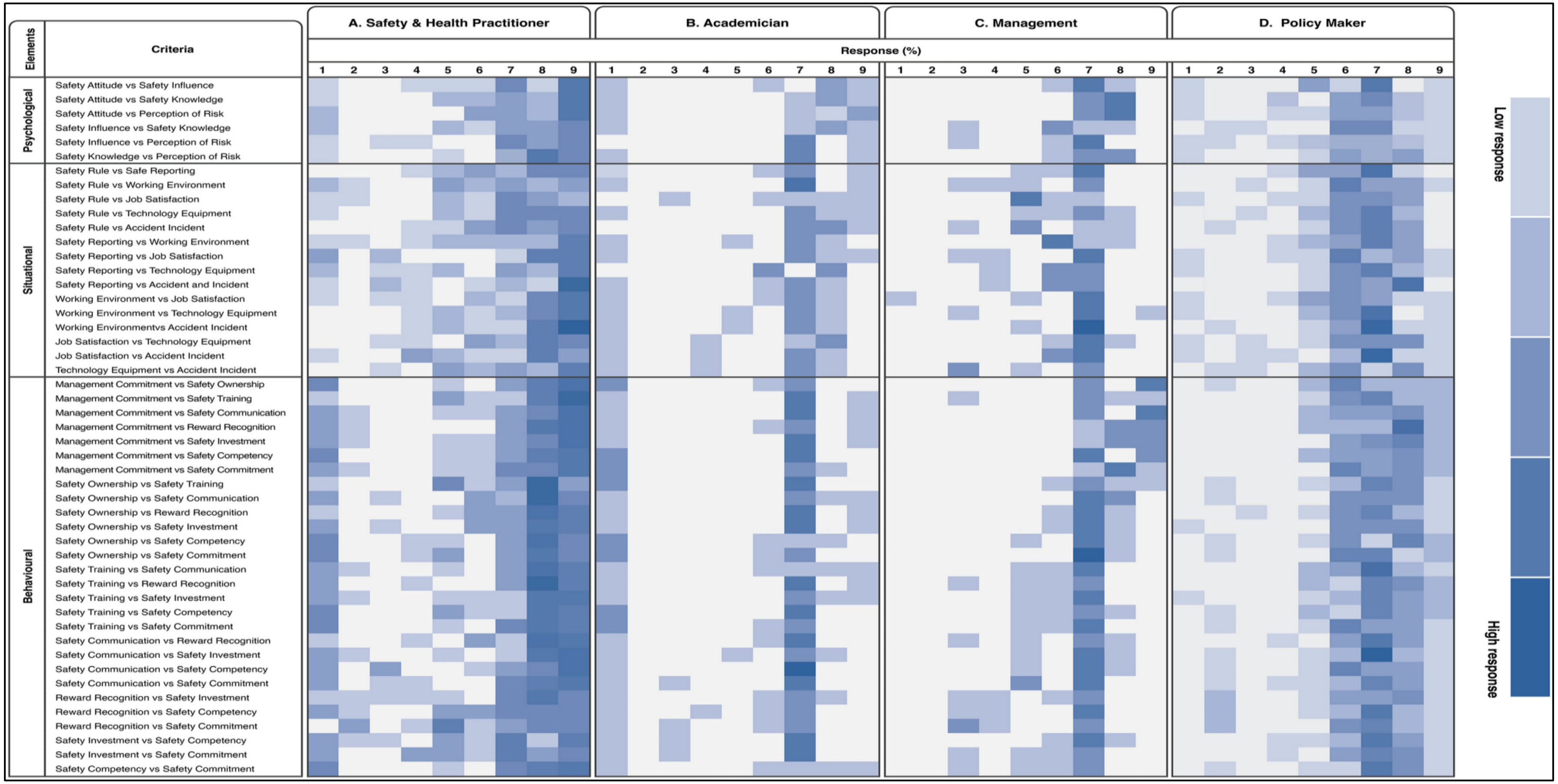

Figure 4.3 Distribution of Study Participants' Response. Government and Regulatory Bodies refer to respondents representing government agencies, regulators, and occupational safety and health authorities. The value "1" represents the highest priority ranking assigned during the AHP pairwise comparison process.

Figure 4.3 illustrates the distribution of stakeholder groups involved in the prioritisation process. The inclusion of respondents from academia, government and regulatory bodies, management personnel, and industry practitioners enabled the study to capture diverse perspectives on safety culture. This multi-stakeholder approach enhances the robustness of the prioritisation process by reducing reliance on a single professional viewpoint. However, the findings should be interpreted within the context of the respondent composition. The "Government and Regulatory Bodies" category comprised respondents from occupational safety and health-related government agencies and regulatory authorities responsible for policy formulation, enforcement, compliance monitoring, and safety governance. These respondents contributed specialised expertise in regulatory requirements, safety management systems, accident prevention, and safety culture implementation across high-risk industries. Their inclusion enabled the study to incorporate regulatory and policy perspectives in addition to the practical insights provided by industry practitioners, management personnel, and academicians, thereby enhancing the comprehensiveness of the prioritisation and validation processes.

Table 4.9 reveals differentiated prioritisation across four key professional groups: Safety & Health Practitioners, Policy Makers, Academicians, and Management. Based on the eigenvector values, the findings underscored distinct emphases aligned with the specific operational roles of each group. Academicians allocated the highest priority to the perception of risk, as evidenced by an eigenvector value of 0.171. This emphasis reflected the intrinsic need for heightened risk awareness in academic environments, where research activities and educational responsibilities necessitated rigorous safety measures. In addition, a significant focus on peer influence was observed among academicians, with an eigenvector value of 0.450. This high value indicated the critical role of peer interaction and collaboration in shaping safety practices within academic settings, hence suggesting that safety behaviours can be heavily influenced by collective norms and peer assessments.

As for management personnel, they exhibited the strongest valuation of safety attitude with an eigenvector value of 0.519. This prioritisation highlighted the pivotal role of organisational leaders in cultivating a proactive safety culture as management commitment to safety attitudes plays a significant role in influencing overall safety practices across the organisation. On the other hand, policy makers demonstrated a pronounced concern for the safety of technology equipment, with an eigenvector value of 0.409. This focus likely stemmed from their regulatory responsibilities to ensure that all technological implementations adhere to established safety standards. Lastly, Safety & Health Practitioners emphasised the importance of management commitment to safety, marked by an eigenvector value of 0.173. Overall, this figure highlighted the critical expectation that safety standards and practices are not only established by leaders but must also be actively enforced and modelled by professionals in leadership roles, particularly in environments where safety is directly linked to operational success. The consistency ratio (CR) was used to evaluate the consistency of expert judgments during the AHP analysis. According to Saaty (1980), a CR value below 0.10 indicates acceptable consistency. The CR values obtained in this study satisfied the recommended threshold, indicating that the expert judgments were sufficiently consistent and reliable for prioritisation purposes.

Table 4.9
Profession Factor Group Preference Elements

Factor group	Criteria	Entire Profession Rank	Safety & Health Practitioner	Policy Maker	Academician	Management
Psychological	Safety attitude	0.300	0.494	0.479	0.260	0.519
	Peer Influence	0.077	0.251	0.294	0.450	0.260
	Safety Knowledge	0.064	0.136	0.094	0.120	0.124
	Perception of risk	0.559	0.119	0.133	0.171	0.097
Situational	Safety rules	0.189	0.071	0.100	0.255	0.258
	Accident Incident	0.161	0.137	0.063	0.082	0.092
	Reporting	0.073	0.104	0.049	0.035	0.062
	Working environment	0.067	0.160	0.127	0.091	0.076
	Job satisfaction	0.250	0.233	0.252	0.233	0.225
	Technology equipment	0.260	0.295	0.409	0.305	0.288
Behavioural	Management commitment	0.088	0.173	0.075	0.117	0.144
	Safety commitment	0.078	0.143	0.088	0.109	0.108
	Safety ownership	0.090	0.100	0.101	0.109	0.143
	Safety training	0.068	0.116	0.120	0.109	0.143
	safety communication	0.068	0.121	0.106	0.146	0.093
	reward recognition	0.189	0.124	0.166	0.145	0.094
	safety investment	0.230	0.100	0.181	0.132	0.137
	Worker competency	0.189	0.124	0.164	0.132	0.138

Note: A higher eigenvector score signifies greater importance or significance attributed to the corresponding criterion

4.4.3 Critical Elements Contributing to a Safety Culture Within Organisations

Table 4.10 delineates the relative importance of various elements spanning the psychological, behavioural, and situational domains. To ascertain the constituents that fall within the top 30% bracket in terms of significance, an analytical approach was adopted. The top 30% threshold corresponded to approximately five elements out of the aggregate of all 18 elements across the three domains. From the results, the most critical elements within the safety culture of an organisation were identified by their eigenvector scores. In the behavioural domain, the elements that stood out included safety investment, safety competency, and reward recognition, with eigenvector scores of 0.23, 0.18, and 0.18, respectively. These elements emphasised the importance of financial commitment to safety practices, as well as the need for skilful execution of these safety measures. Compliance with safety measures should be incentivised through recognition and rewards. In the situational domain, technology/equipment and job satisfaction were identified as paramount, scoring eigenvector scores of 0.26 and 0.25, respectively. The high score for technology/equipment indicated the critical need for up-to-date and safe operational tools, while job satisfaction highlighted the correlation between employees' contentment and their adherence to safety protocols. Based on this analysis, these five elements have been pinpointed as key focus areas for organisations to enhance their safety culture.

Table 4.10
Calculation of Psychological, Behavioural and Situational Preference

Variable		Normalize Matrix								Eigenvector	Rank
		B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**		
Behavioural	**B1**	0.06	0.06	0.25	0.06	0.06	0.03	0.05	0.10	0.08	9
	B2	0.06	0.06	0.16	0.06	0.06	0.03	0.05	0.10	0.07	11
	B3	0.02	0.03	0.08	0.06	0.06	0.14	0.10	0.20	0.09	7
	B4	0.06	0.06	0.08	0.06	0.06	0.03	0.05	0.10	0.06	14
	B5	0.06	0.06	0.08	0.06	0.06	0.03	0.05	0.10	0.06	14
	B6	0.27	0.27	0.08	0.26	0.26	0.14	0.1	0.10	0.18	4
	B7	0.27	0.27	0.16	0.26	0.26	0.28	0.20	0.10	0.23	3
	B8	0.13	0.13	0.08	0.13	0.13	0.28	0.40	0.20	0.18	4
		S1	**S2**	**S3**	**S4**	**S5**	**S6**				
Situational	**S1**	0.16	0.41	0.15	0.12	0.13	0.13			0.18	4
	S2	0.04	0.10	0.23	0.31	0.13	0.13			0.16	6
	S3	0.08	0.03	0.07	0.06	0.09	0.09			0.07	11
	S4	0.08	0.02	0.07	0.06	0.09	0.06			0.06	14
	S5	0.32	0.20	0.23	0.18	0.27	0.27			0.25	2
	S6	0.32	0.20	0.23	0.25	0.27	0.27			0.26	1
		P1	**P2**	**P3**	**P4**						
Psychological	**P1**	0.06	0.06	0.25	0.06					0.08	9
	P2	0.06	0.06	0.16	0.06					0.07	11
	P3	0.02	0.03	0.08	0.06					0.09	7
	P4	0.06	0.06	0.08	0.06					0.06	14

Note: The table presents the normalized pairwise comparison matrices for behavioural, situational, and psychological elements, followed by their corresponding eigenvector weights and ranking. Higher eigenvector values indicate greater relative importance of each element within its respective domain.

To achieve a more comprehensive understanding of complex decision-making situations or performance evaluations, the Importance-Performance Analysis (IPA) was conducted. The IPA matrix categorised 18 key safety culture elements into four distinct quadrants, each representing different strategic implications (Figure 4.4). The matrix highlighted that 22% of the elements belonged in the High Importance-High Performance (Maintain) quadrant, suggesting that these are well-managed areas crucial for safety culture, such as 'Technology Equipment' and 'Safety Investment', that should continue to receive sustained attention and resources.

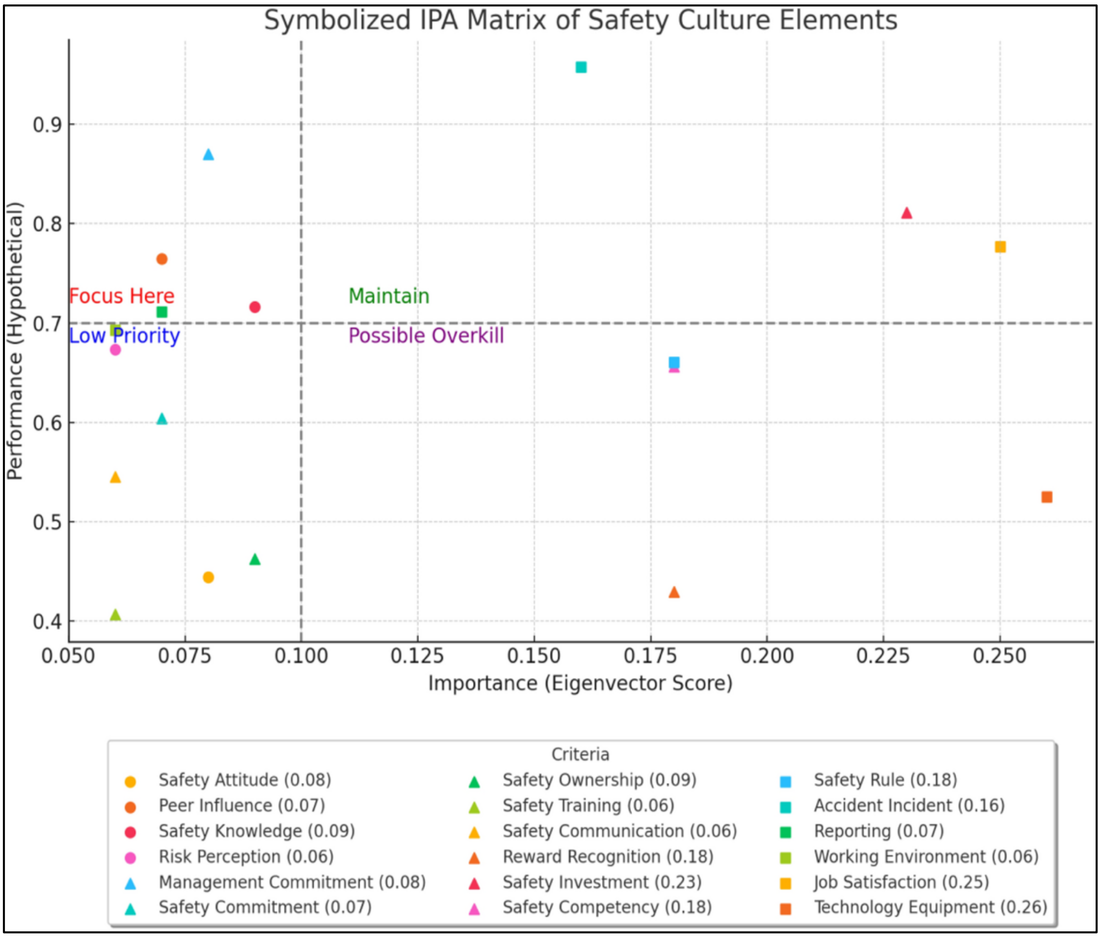

Figure 4.4 Importance–Performance Analysis (IPA) of Safety Culture Elements Using Eigenvector Weights. Note: The matrix maps 18 safety culture indicators according to their calculated importance (derived from AHP eigenvector scores) and their corresponding performance levels. Elements positioned in the *Focus Here* quadrant represent critical areas needing immediate improvement due to high importance but lower performance. Indicators in the *Maintain* quadrant demonstrate strong performance in high-importance areas. The *Low Priority* quadrant reflects elements of lesser strategic significance, while the *Possible Overkill* quadrant identifies areas where performance exceeds the level of importance. This visualization supports targeted resource allocation and strategic enhancement of safety culture practices.

Conversely, 28% of the elements were categorised under the High Importance-Low Performance (Focus Here) quadrant. This included critical but underperforming elements like 'Management Commitment' and 'Safety Rule', indicating a pressing need for targeted improvement and increased resource allocation. Interestingly, 17% of the elements were placed in the Low Importance-High Performance (Possible Overkill) quadrant, such as 'Safety Communication', suggesting that these elements might be receiving more resources than necessary given their current importance and indicating potential reallocation to more critical areas. Finally, 33% of the elements were considered under the Low Importance-Low Performance (Low Priority) quadrant, including 'Risk Perception' and 'Accident Incident'. Even though deemed as less crucial, these elements showed poor performance and required minimal investment. They should also be monitored for any significant trend changes that could alter their strategic importance.

Table 4.11 provides a structured analysis to show the weighting of safety culture preference elements among the psychological, behavioural, and situational factors. The importance of each element was assessed using the AHP, resulting in normalised eigenvector values that signified their respective weights in fostering a robust safety culture. Behavioural elements emerged as the most influential, with the highest eigenvector value (0.53). Behavioural factors directly influence daily operations and cast a tangible impact on the overall safety culture. Situational elements involving external and environmental conditions that affected the organisation came in next (Eigenvector = 0.29). While not as directly impactful as behavioural elements, situational elements often create a foundational context that either enables or hinders safety behaviours. Lastly, although ranked lowest, psychological factors remained vital (Eigenvector = 0.16). They encompassed attitudes, perceptions, and the mental readiness of employees towards safety, such as the psychological safety of speaking up about hazards without fear of retribution. Despite their lower weights, these elements were crucial for sustaining a safety culture.

Table 4.11
Weighting of Safety Culture Preference Elements

Variable	**Normalized Matrix**			**Eigenvector**	**Prioritisation**
	Psychological	Behavioural	Situational		
Psychological	0.16	0.18	0.14	0.16	3
Behavioural	0.50	0.54	0.57	0.53	1
Situational	0.33	0.27	0.28	0.29	2

Note: The safety culture elements are categorised with: P=Psychological, B=Behavioural, S=Situational

4.4.4 Discussion

This research set out to refine existing safety culture frameworks by analysing the preference elements for organisational improvement in the Malaysian oil and gas industry. Previous research has consistently highlighted the importance of these components in maintaining a robust safety culture across various industries (Van Nunen 2022 et al., 2022 and Schulman, 2020). In line with these findings, our study conducted a detailed comparative analysis of how different professionals within the oil and gas industry prioritise various aspects of safety culture. This approach is crucial for developing customised safety strategies that cater to the specific needs of diverse stakeholder groups, leading to more targeted and effective safety interventions in the sector.

The current study's findings align with earlier research that emphasizes the importance of practical safety measures and management commitment in establishing a strong safety culture. For instance, Safety & Health Practitioners in our study prioritised practical safety rules and management commitment, which mirrors the past findings of where top-down enforcement of safety standards was seen as essential in high-risk environments (Hafeez et al., 2022 and Bisbey et al., 2021). This focuses on practical measures is particularly vital in industries where procedural adherence directly influences safety outcomes. In contrast, academicians in our study placed greater emphasis on theoretical aspects such as safety knowledge and training, which complements existing frameworks that identify education and awareness as foundational elements of safety culture (Deepak et al., 2024 and Omidi et al., 2022). This finding underscores the role of a well-informed workforce in effectively integrating safety practices into daily operations. Moreover, management's emphasis on safety ownership and communication in our study is consistent with modern safety culture frameworks that stress the importance of leadership involvement in cultivating a proactive safety culture (Naji et al., 2022, Bazzoli et al., 2021, Abatan et al., 2024 and Di Fiore et al., 2023). Additionally, policymakers in our study showed a preference for technological and equipment safety, reflecting a macro-level approach that aligns with previous studies highlighting the role of regulatory frameworks and technological advancements in enhancing industry safety standards (Lie et al., 2021, Othman et al., 2020 and Wanasinghe et al., 2021).

As reported in previous research, behavioural elements are crucial in cultivating safety culture within oil and gas organisations (Parker et al., 2006). Our study reinforces this perspective by emphasizing the significance of tangible actions in improving safety outcomes. This finding aligns with the reciprocal model of safety culture, which suggests that the interplay between organisational culture and individual behavioural significantly influences safety outcomes (Cooper, 2000). Our findings further support this model by highlighting the importance of situational factors, i.e., external and environmental conditions, as key areas for intervention. Even though psychological elements appeared to be less influential in our framework, their importance cannot be side lined. Past research suggests that although psychological aspects are less visible, they remain fundamental to safety culture and should not be neglected in strategies aimed at cultivating a safety culture (Guldenmund, 2000). Our study echoes this sentiment, highlighting the need for an integrated approach that combines behavioural, situational, and psychological elements to create a robust safety culture in the oil and gas sector.

Moreover, this study also highlights the differential prioritisation of these elements in cultivating a safety culture, with specific implications for enhancement strategies. Behavioural aspects, focusing on modifying employee behavioural and fostering intrinsic motivation towards safety compliance, align with safety culture frameworks that support bottom-up, behavioural-driven approaches (Ehiaguina and Moda, 2020 and Abdullah, 2022). Situational factors emphasize enhancing the physical and organisational environment to support safe practices, facilitating a conducive setting for safety (Di Prinzo et al., 2020). Although psychological elements were less prioritised, they are still fundamental, with effective safety culture strategies promoting psychological safety, enabling employees to express safety concerns freely and fostering a safety-first mindset. An integrated approach that combines all three elements is necessary to address dynamic industry challenges, ensuring that safety culture enhancement remains a central organisational focus supported by continuous refinement and responsive leadership practices (Xue et al., 2020). In other words, enhancing safety culture in the oil and gas industry should be a multifaceted endeavour, addressing direct actions (behavioural), the enabling environment (situational), and foundational attitudes (psychological). By adopting a comprehensive approach, the industry can significantly mitigate risks and enhance overall safety performance, cultivating a resilient and proactive safety culture.

Given the high-risk nature of the oil and gas industry, enhancing safety culture strategies through several key approaches is imperative. Substantial investments in industry-specific training and resources are crucial for strengthening risk management and accident prevention (Xin et al., 2020 and Roy et al., 2020). The adoption of advanced safety technologies and regular maintenance of equipment standards are essential to prevent operational failures (Odili et al., 2024) Moreover, the strong link between job satisfaction and safety outcomes calls for management practices that promote effective communication and a supportive environment, allowing employees to raise safety concerns freely (Dziuba et al., 2020 Obiora et al., 2023). At the same time, stringent regulatory oversight is required to ensure compliance and maintain high safety standards across the industry (Yang, 2023 and Nævestad et al., 2021). Aligning these safety culture enhancement strategies with the specific preferences and priorities of diverse stakeholder groups is crucial. By focusing on these areas, the industry can achieve a more effective and resilient safety culture that not only meets but exceeds regulatory standards, safeguarding the well-being of its workforce.

This study utilised the Importance-Performance Analysis (IPA) matrix to assess the relevance and efficacy of 18 safety culture criteria across psychological, behavioural, and situational dimensions within organisations. This method allows for the identification of areas needing improvement and facilitates targeted budget and resource allocation to maximize safety outcomes. Our findings provide a detailed understanding of organisational safety culture, highlighting key areas where strategic interventions can significantly enhance safety performance. The IPA matrix serves as a guide for prioritising resources towards high-impact areas while recommending reduced investment in less important and/or over-performing areas**.** This strategy aligns with recent research that stresses the importance of resource allocation in safety management, pointing out that optimized resource distribution can lead to substantial improvements in safety practices (Wang et al., 2024). Particularly, this study emphasizes the need to enhance elements within the High Importance-Low Performance quadrant to mitigate risks and improve overall safety culture practices (Xu et al., 2023). Conversely, identifying over-invested elements in the Low Importance-High Performance quadrant offers vital insights into potential cost savings, a critical measure during budget constraints (Roy, 2022). Overall, the IPA matrix serves not only as a resource allocation guide but also as a reflective tool for continuous safety culture improvement, applying a dynamic approach to safety management that adapts to changing organisational needs.

Following the integration of the Analytic Hierarchy Process (AHP) with IPA, a nuanced relationship emerged between structured decision-making and performance evaluation methodologies. AHP, known for its hierarchical structuring of decision criteria, provides a robust framework for establishing the relative importance of various factors within a decision context. Conversely, IPA focuses on assessing the importance and performance of individual attributes or factors, often within the domain of customer satisfaction or organisational performance. When elements identified in AHP diverge from those in IPA, it may indicate a disparity in focus and purpose, reflecting the distinct objectives between the two methodologies. While AHP assists in decision-making processes, IPA serves as a tool for performance evaluation and improvement. The variation in identified elements between AHP and IPA sheds light on the nuanced interplay between structured decision analysis and performance assessment, highlighting their complementary roles in facilitating comprehensive decision-making and performance management initiatives.

This research provided a comprehensive overview of strategies for enhancing safety culture in the oil and gas industry, primarily focusing on the differential prioritisation of behavioural, situational, and psychological elements based on the SMEs in the industry. However, there are several limitations of the current study that can be addressed in future research to further refine safety culture strategies. While the study discusses each element individually, the complex interdependencies between behavioural, situational, and psychological factors were not fully explored. The interactions between these elements can significantly influence the effectiveness of safety culture enhancement strategies. Therefore, future research should focus on the complex interdependencies between behavioural, situational, and psychological elements. For instance, systems thinking approaches or network analysis can be applied to map out and quantify these interactions, ultimately pinpointing key leverage points where interventions can be most effective.

4.4.5 Conclusion

In summary, this study provides a comprehensive analysis of the multifaceted nature of psychological, behavioural, and situational factors that significantly influence safety culture dynamics within the Malaysian oil and gas sector. By employing the Analytic Hierarchy Process (AHP), the research successfully identified and prioritised key elements of safety culture as perceived by various stakeholders. The findings highlight the complexity of safety culture, where each factor plays a critical role in shaping the overall safety environment. The study's results reveal the hierarchical structure of these factors, emphasizing the importance of addressing both individual attitudes and behavioural, as well as organisational and environmental conditions, to foster a robust safety culture. The psychological factors, including personal attitudes towards safety and risk perception, were found to be crucial in determining how safety practices are adopted and internalized by employees. Similarly, the behavioural elements, such as management commitment and employee safety ownership, were shown to have a direct impact on the effectiveness of safety interventions and the overall safety performance of the organisation. Situational factors, encompassing the physical working environment, safety rules, and reporting systems, were also identified as pivotal in sustaining a safety culture that promotes continuous improvement and adaptability to changing conditions. The study underscores the need for organisations to adopt a holistic approach to safety management, where psychological, behavioural, and situational factors are integrated into safety strategies.

The insights generated from this study provide valuable guidance for organisations in the oil and gas industry, and potentially other high-risk sectors, on how to effectively allocate resources and prioritise interventions that will yield the greatest impact on safety performance. By understanding the relative importance of these factors, organisations can tailor their safety programs to address the specific needs and preferences of their workforce, thereby enhancing the overall safety culture and reducing the likelihood of accidents and incidents. Furthermore, the application of the AHP methodology in this context demonstrates its utility as a decision-making tool that can be used to systematically evaluate complex, multi-criteria scenarios. This approach not only provides a structured framework for prioritising safety initiatives but also ensures that the perspectives of all relevant stakeholders are considered in the decision-making process. In conclusion, this study contributes to the broader understanding of safety culture in high-risk industries by offering a nuanced perspective on the factors that drive safety performance. The findings have practical implications for safety practitioners, managers, and policymakers who are tasked with improving workplace safety outcomes. As organisations continue to navigate the challenges of maintaining a strong safety culture, the insights provided by this research will be instrumental in guiding effective and sustainable safety interventions.

4.5 Aim 4: Modelling the Architecture of Safety Culture: Psychometric Validation and Predictors of Safety Outcomes in Malaysian Industries[7]

Safety culture is widely recognised as a foundational determinant of occupational safety performance, particularly in high-risk industries where operational complexity, hazardous environments, and human–system interactions elevate the likelihood of accidents and organisational failures (Cidik et al., 2021 and Nævestad, 2009). Over the past decades, global research has consistently shown that safety culture shapes workers' perceptions, behaviours, and involvement in safety practices, exerting a direct influence on incident rates, compliance, and overall operational resilience (Ying et al., 2025, Zhang et al., 2005 and Yazdi, 2025). Traditional interventions have largely focused on improving compliance, enhancing training, or strengthening management oversight (Friday et al., 2022); however, these efforts often fail to capture the multidimensional nature of safety culture, which encompasses psychological dispositions, behavioural practices, and situational or environmental conditions that workers experience on a daily basis (Bisbey et al., 2021).

Existing studies have attempted to address these challenges through various approaches, such as prioritising safety elements, assessing leadership influence, and introducing behavioural-based safety programmes (Sinha et al., 2021, Wamuziri, 2013, and Jespersen et al., 2016). Our previous work, for example, identified behavioural and situational components such as safety training, rule compliance, work environment, and technology/equipment as the most influential determinants of safety culture within

[7] Rahim, H., Che Dom, N., Dapari, R., & Hamid. M.R. (2025). Multidimensional Safety Culture and Its Influence on Safety Performance: Evidence from Structural Equation Modelling. *Humanities and Social Sciences Communications*. (Submitted: 23rd Nov 2025. Under Review).

Malaysia's oil and gas sector (Rahim et al., 2024). While these prioritisation studies provide valuable insights into which elements matter most, they do not empirically model how these components interact or how they collectively shape safety outcomes. Thus, despite progress in identifying key predictors, a significant methodological gap remains: few studies have validated safety culture as a higher-order structural construct or examined how demographic, educational, occupational, and sectoral factors influence its underlying dimensions (Amirah et al., 2024 and Naji et al., 2021). This gap is especially important in Malaysia, where rapid industrial growth across oil and gas, manufacturing, and service sectors has intensified the need for a more robust understanding of safety culture mechanisms (Al Mazrouei et al., 2019). Local industries continue to face persistent challenges such as inconsistent safety compliance, limited safety ownership, varied training quality, and structural constraints related to reporting systems and environmental conditions (Baghdadi, 2024). These issues highlight the need for an integrated analytical framework that not only captures the complexity of safety culture but also identifies how different organisational and worker-level characteristics contribute to safety performance.

The objective of this study is therefore to develop and validate a comprehensive higher-order model of safety culture using Structural Equation Modelling (SEM), building upon the theoretical and empirical foundations of our previously validated safety culture instrument. Specifically, the study aims to: (i) evaluate the measurement validity of psychological, behavioural, and situational safety dimensions; (ii) examine the structural relationships among these constructs; and (iii) determine how demographic and organisational predictors such as education, occupation, sector, and OSH involvement shape overall safety outcomes. By integrating prioritisation findings with rigorous psychometric validation, this study seeks to advance safety culture research beyond descriptive or element-based evaluations toward a unified structural understanding of how attitudes, behaviours, and environmental conditions collectively influence safety performance. The resulting model provides a robust empirical foundation for designing targeted, multi-level safety interventions tailored to high-risk Malaysian industries and potentially applicable across global industrial settings.

4.5.1 Predictors of Safety Outcomes

The structural equation modelling (SEM) results in the present study extend our earlier work on safety culture prioritisation in the Malaysian oil and gas industry, where the Analytical Hierarchy Process (AHP) identified behavioural and situational elements as the most influential components of safety culture compared to psychological factors (Rahim et al., 2024). In that study, behavioural elements such as management commitment, safety ownership, and safety training, as well as situational elements such as safety rules, technology/equipment, and job satisfaction, emerged as high-priority contributors to organisational safety performance. The current SEM model empirically validates these patterns by demonstrating that the higher-order constructs, namely Psychological Safety, Behavioural Safety, and Situational Safety, load strongly onto their respective indicators and collectively shape overall safety outcomes. Importantly, the SEM paths reinforce the dominance of behavioural and situational components observed in the AHP analysis, suggesting that workers' day-to-day behaviours and the surrounding organisational environment remain the critical drivers of safety culture, beyond attitudinal or psychological dispositions.

Random-effects regression analysis was conducted to identify demographic, educational, occupational, sectoral, and involvement-related predictors of overall safety outcomes. Table 4.12 summarises the standardised coefficients (β), standard errors, t-values and p-values for each predictor. Several predictors emerged as significant determinants of safety outcomes. Among demographic variables, gender and age demonstrated non-significant associations ($p \geq 0.05$). In contrast, multiple education categories showed meaningful positive effects. Compared to the reference group, respondents with a Bachelor's degree exhibited a modest but significant improvement in safety outcomes ($\beta = 0.06$, $p = 0.05$). Higher academic qualifications further strengthened this association, with Master's degree holders ($\beta = 0.10$, $p = 0.01$) and PhD holders ($\beta = 0.12$, $p = 0.02$) demonstrating the strongest educational influence. Occupational role also played a significant part in shaping safety performance. Individuals employed as Safety & Health Practitioners had substantially higher safety outcome scores ($\beta = 0.10$, $p = 0.01$), while Managers or Representatives showed moderate but significant effects ($\beta = 0.08$, $p = 0.05$). Sectoral differences were evident, with respondents from both the manufacturing sector ($\beta = 0.06$, $p = 0.05$) and the health sector ($\beta = 0.08$, $p = 0.05$) reporting significantly elevated safety outcomes.

Additionally, OSH involvement emerged as a strong independent predictor (β = 0.10, p = 0.01), indicating that active participation in occupational safety and health initiatives contributes meaningfully to improved safety performance. In this study, safety outcome refers to the overall effectiveness of safety culture practices as reflected through respondents' perceptions of safety performance indicators. The safety outcome construct was measured using questionnaire items adapted from established safety culture literature and was subsequently analysed against socio-demographic variables to examine potential differences among respondent groups.

Table 4.12
Random-Effects Regression Estimates of Predictors Influencing Safety Outcomes

Variable	**Coefficient (β)**	**SE**	**t-value**	**p-value**	**Significance**
Gender (Male)	0.050	0.030	1.670	0.090	–
Age	-0.001	0.000	-1.560	0.120	–
Education Background					
Professional Certificate	0.070	0.040	1.750	0.080	–
Bachelor Degree	0.060	0.030	2.000	0.050	*
Master Degree	0.100	0.040	2.500	0.010	**
PhD	0.120	0.050	2.400	0.020	**
Occupation					
Safety & Health Practitioner	0.100	0.040	2.500	0.010	**
Manager / Rep	0.080	0.040	2.000	0.050	*
Sector					
Oil and Gas	0.060	0.030	2.000	0.050	*
Others	0.080	0.040	2.000	0.050	*
OSH Involvement	0.100	0.040	2.500	0.010	**

Note: The table presents standardised coefficients (β), standard errors (SE), t-values, and p-values from the random-effects model. Asterisks denote levels of statistical significance ($p < 0.05$ = *, $p < 0.01$ = **). Positive β values indicate a stronger positive association between the variable and overall safety outcomes. Education, occupation, and sector categories are treated as reference group comparisons within each classification.

The relatively higher standard errors observed within certain education categories may be attributed to variations in respondent distribution and sample size across groups. Respondents with higher educational qualifications may also possess more diverse professional experiences and perspectives on safety culture, resulting in greater variability in responses. Higher standard error values indicate greater dispersion of responses rather than stronger effects or relationships. Therefore, these findings should be interpreted cautiously and primarily as indicators of response variability within the respective demographic groups. A visual summary of all individual and category-level predictors is provided in Figure 4.5. In Panel A, coefficient plots illustrate the magnitude and direction of each predictor along with their 95% confidence intervals, while Panel B aggregates mean standardised β values across education, occupation, and sector categories to highlight broader trends in predictor influence.

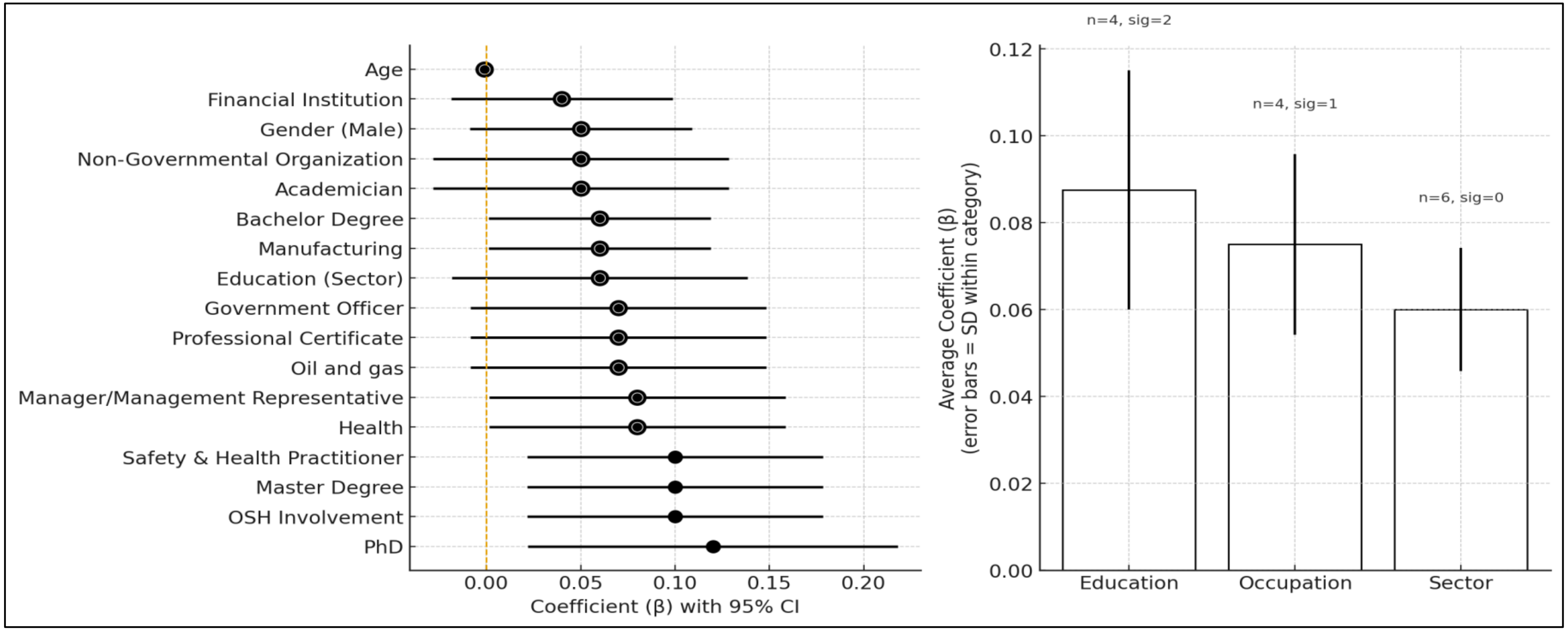

Figure 4.5 Coefficient and Category-Level Summary of Predictors Influencing Safety Outcomes. Note: Panel A presents the standardised coefficients (β) with 95% confidence intervals for all individual predictors. Filled circles indicate significant predictors ($p < 0.05$), solid squares denote highly significant predictors ($p < 0.01$), and hollow circles represent non-significant predictors ($p \geq 0.05$). The dashed vertical line indicates the null effect ($\beta = 0$). Panel B summarises the mean standardised coefficients (β) across predictor categories (Education, Occupation, and Sector), with error bars representing within-category standard deviations. The annotations above each bar show the number of variables (*n*) and count of significant predictors (sig). The value n represents the number of categories within each demographic variable included in the analysis. For example, education and occupation comprised four categories, while sector consisted of six categories

4.5.2 Measurement Model Evaluation

The measurement model assessing the three higher-order safety constructs; Psychological Safety, Behavioural Safety, and Situational Safety was evaluated through standardised factor loadings, composite reliability (CR), and average variance extracted (AVE) to determine construct validity and internal consistency (Table 4.13). Overall, the results demonstrated that all three latent constructs met the minimum psychometric criteria, indicating that the indicators adequately represented their respective domains.

For Psychological Safety, the construct exhibited strong internal reliability (CR = 0.84) and acceptable convergent validity (AVE = 0.58), reflecting a coherent and well-specified latent dimension. Among the observed indicators, *safety attitude* emerged as the single strongest contributor (loading = 0.502), suggesting that workers' positive beliefs and perceptions about safety practices represent the core component of psychological safety. This was followed by *safety influence* (0.238), capturing the extent to which individuals perceive safety norms as influential within the work environment, and *safety knowledge* (0.135), indicating a smaller yet meaningful contribution related to workers' awareness and understanding of safety procedures. The loading pattern suggests that psychological safety in this context is primarily shaped by attitudinal elements rather than knowledge-driven components, highlighting the importance of fostering positive safety mindsets in strengthening psychological safety climates.

The Behavioural Safety construct similarly demonstrated satisfactory psychometric properties, with CR = 0.82 and AVE = 0.55, indicating that the set of behavioural indicators collectively explained more than half of the variance in the construct. *Safety training* emerged as the most influential factor (loading = 0.391), emphasizing the critical role of structured learning and skill acquisition in shaping safe work behaviours. Other indicators showed progressively smaller contributions, including *safety communication* (0.258), *reward recognition* (0.164), *safety investment* (0.135), and *safety competency* (0.108). Meanwhile, several managerial-related indicators, such as *management commitment*, *safety ownership*, and *safety commitment*, remained constrained or exhibited non-significant paths. Collectively, these findings indicate that behavioural safety within the studied setting is driven more strongly by operational and training-related efforts rather than supervisory or incentive-based mechanisms, underscoring the value of skill development and clear communication channels in cultivating safer work behaviours.

Among the three constructs, Situational Safety displayed the strongest psychometric performance, with the highest composite reliability (CR = 0.86) and convergent validity (AVE = 0.60). This indicates that its indicators reliably captured environmental and contextual features of the safety system. *Safety rule compliance* dominated the construct with a substantial loading of 0.736, demonstrating that adherence to established safety regulations is the most defining element of situational safety. Additional indicators contributed moderately to the construct, including *safety reporting* (0.362), *work environment* (0.286), *job satisfaction* (0.229), *technology and equipment* (0.163), and *accident or incident experience* (0.107). The overall loading structure suggests that situational safety is largely determined by rule-based and environmental aspects of the workplace rather than personal experience or satisfaction levels. These results highlight the importance of strong regulatory compliance, robust reporting systems, and conducive work environments in shaping situational safety outcomes. Taken together, the measurement model results confirm that all three higher-order safety constructs are adequately represented by their respective indicators, with each construct emphasizing different dimensions of occupational safety: attitudinal components for psychological safety, training-driven behaviours for behavioural safety, and structural/environmental conditions for situational safety.

Table 4.13
Results of Factor Loadings, Composite Reliability (CR) and Average Variance Extracted (AVE) for the Higher-Order Safety Constructs.

Constructs	**Higher order**	**Items**	**Loading**
Psychology Safety	CR = 0.84 AVE = 0.58	Safety Attitude	0.502
		Safety Influence	0.238
		Safety Knowledge	0.135
		Management Commitment	0.694
		Safety Ownership	0.391
Behavioural Safety	CR = 0.82 AVE = 0.55	Safety Training	0.391
		Safety Communication	0.258
		Reward Recognition	0.164
		Safety Investment	0.135
		Safety Competency	0.135
		Safety Commitment	0.108
Situational Safety	CR = 0.86 AVE = 0.60	Safety Rule	0.736
		Safety Reporting	0.362
		Work Environment	0.286
		Job Satisfaction	0.229
		Technology Equipment	0.163
		Accident Incident	0.107

Note: This table presents the standardised factor loadings of all observed indicators on their respective higher-order constructs: *Psychology Safety*, *Behavioural Safety*, and *Situational Safety*. The loadings indicate the relative contribution of each item to the corresponding latent construct. Composite reliability (CR) values above 0.70 and AVE values above 0.50 demonstrate acceptable construct reliability and convergent validity. Items with missing loadings (-) represent non-significant or constrained paths in the model.

4.5.3 Structural Equation Model Findings

The Structural Equation Model (SEM) provided a comprehensive and visually compelling representation of the interrelationships among the three higher-order safety constructs; Psychological Safety, Behavioural Safety, and Situational Safety and their respective observed indicators, as illustrated in Figure 4.6. Each latent construct was measured by a distinct cluster of indicators: psychological safety by three observed variables (e1–e3), behavioural safety by eight indicators (e4–e11), and situational safety by six indicators (e12–e17), reflecting the multidimensional nature of safety culture within the occupational environment. The standardised factor loadings aligned closely with those reported in Table 2, reinforcing the strong internal consistency and robustness of the measurement model.

The structural configuration of the model highlights how each safety dimension plays a distinct yet complementary role within the broader safety ecosystem (Figure 4.6). Psychological safety emerged as a predominantly attitudinal construct, with the strongest contributions derived from workers' safety beliefs, perceptions, and internalized norms. Behavioural safety, in contrast, was driven primarily by training-related and communication-based mechanisms, indicating that practical skill acquisition, safety messaging, and day-to-day behavioural reinforcement form the backbone of safe work practices. Meanwhile, situational safety was heavily shaped by rule compliance and workplace conditions, underscoring the critical influence of environmental structures, physical resources, and adherence to established procedures. When interpreted alongside the regression findings, the SEM results offer a powerful and integrated view of how both individual-level attributes and organisational factors shape safety outcomes. Educational attainment, occupational role, sectoral engagement, and OSH involvement emerged as meaningful predictors of safety performance, yet the structural model reveals that the *mechanisms* through which these factors exert influence differ across psychological, behavioural, and situational dimensions. Together, these results underscore that safety culture is not a monolithic entity but a finely layered system in which attitudes, behaviours, and environmental conditions converge to determine overall safety performance. This integrated framework provides a strong empirical foundation for designing targeted, dimension-specific interventions that enhance safety culture at multiple levels within high-risk industries. The SEM results demonstrated significant relationships among the psychological, behavioural, and situational dimensions of safety culture. Among these dimensions, the behavioural construct exhibited the strongest contribution to the overall safety culture framework, indicating that behavioural factors play a central role in influencing safety culture outcomes. The findings support the multidimensional nature of safety culture proposed in previous studies and provide empirical justification for focusing BOSCA on behavioural safety culture elements.

The SEM analysis demonstrated significant interrelationships among psychological, behavioural, and situational dimensions of safety culture. The behavioural construct exhibited the strongest contribution to the overall framework, indicating its central role in influencing safety culture outcomes. This finding is consistent with previous studies reporting that behavioural factors often serve as the operational mechanism through which psychological perceptions and organisational conditions are translated into safety-related actions and performance outcomes. The findings support Cooper's Reciprocal Safety Culture Model, which emphasises the interaction between psychological, behavioural, and situational dimensions of safety culture. The results also align with Hudson's Safety Culture Maturity Model, where management commitment and behavioural practices are recognised as critical drivers of proactive safety culture development. The dominance of behavioural factors identified in this study further supports behavioural safety theories that emphasise observable safety practices as key determinants of organisational safety performance.

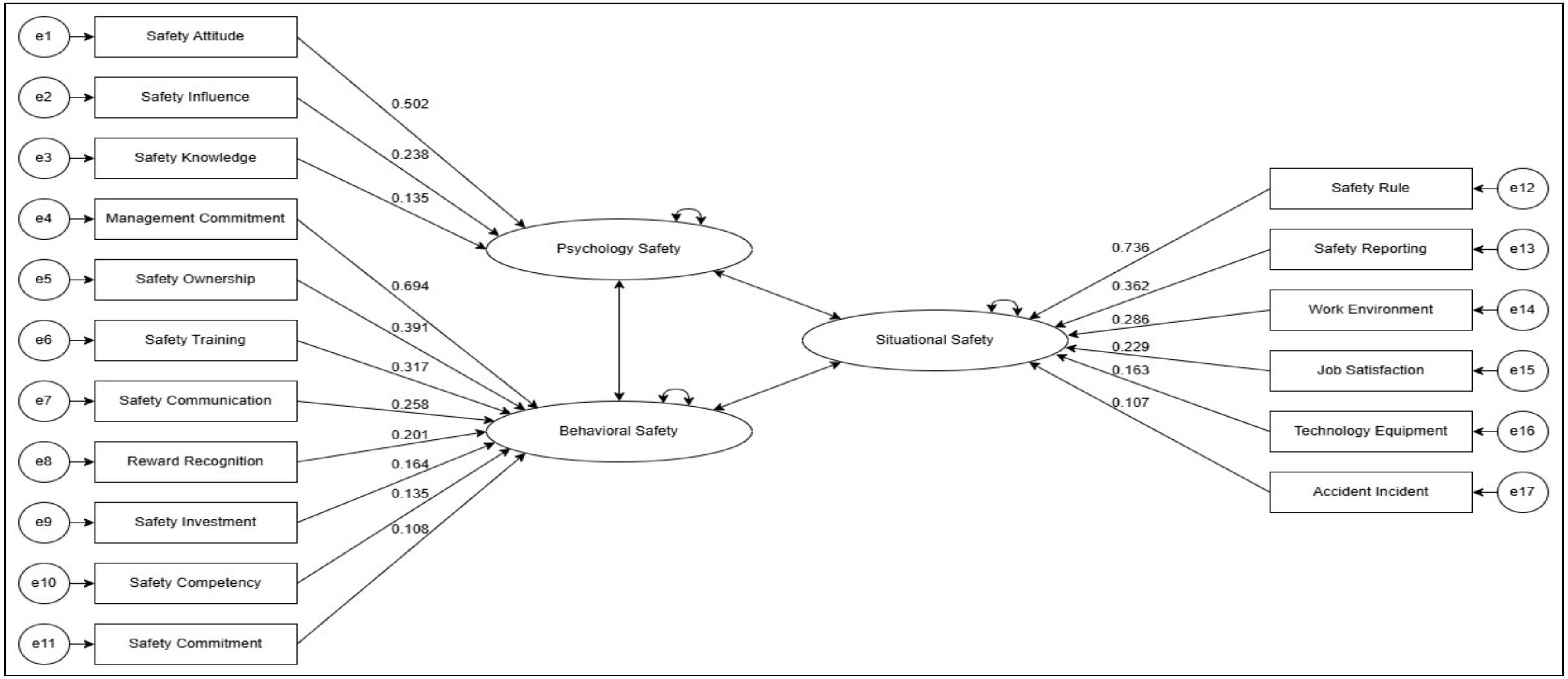

Figure 4.6 Structural Equation Model Illustrating the Relationships Among Psychological Safety, Behavioural Safety and Situational Safety. Standardised factor loadings are displayed along each path. Note Indicators for psychological safety include safety attitude, influence, and knowledge (e1–e3). Behavioural safety is represented by management commitment, ownership, training, communication, reward recognition, investment, competency, and commitment (e4–e11). Situational safety is measured through safety rule, reporting, work environment, job satisfaction, technology equipment, and accident incident (e12–e17). Arrows denote directional effects between latent constructs and observed variables.

4.5.4 Discussion

This study advances the understanding of safety culture by validating a higher-order structural framework comprising psychological, behavioural, and situational dimensions while integrating individual and organisational predictors of safety outcomes. The findings provide strong empirical coherence with our earlier prioritisation study, in which behavioural and situational components were ranked as the most influential contributors to safety culture in the oil and gas sector. The present SEM analysis not only reinforces those patterns but also offers a statistically robust explanation of how these dimensions interact to shape safety performance. Although previous studies frequently highlight safety training and safety communication as dominant behavioural drivers of safety culture, the present study identified management commitment as the strongest behavioural contributor. This finding suggests that leadership support and visible management involvement may serve as foundational enablers that influence the effectiveness of other behavioural safety practices, including communication, training, ownership, and employee engagement. In the context of the Malaysian oil and gas industry, management commitment may have a greater influence because organisational safety priorities, resource allocation, and employee participation in safety initiatives are often driven by leadership decisions. Consequently, strong management commitment may strengthen the implementation and effectiveness of other behavioural safety culture elements.

Education emerged as a powerful determinant of safety outcomes, with Master's and PhD holders demonstrating significantly higher scores (Ali et al., 2023). This suggests that advanced academic training may enhance hazard interpretation, procedural understanding, and adherence to safe practices (Elete et al., 2024, Hopkins, 2011 and Albert et al., 2021). Likewise, Safety & Health Practitioners reported substantially higher safety performance, reflecting the impact of specialised training and exposure to risk management tasks (Sujan et al., 2016). OSH involvement also showed strong positive effects, indicating that active participation in safety programmes cultivates shared ownership and deepens workers' commitment to safe operations (Fu et al., 2025). These patterns collectively highlight the importance of professionalisation, continuous development, and participatory governance in strengthening safety systems.

The SEM measurement model demonstrates that the safety culture framework is not monolithic but comprises distinct mechanisms. Psychological Safety was mainly defined by attitudinal elements, indicating that workers' beliefs and perceptions regarding safety form the emotional–cognitive base of safe behaviour (Sun et al., 2022 and Itzchakov et al., 2022). However, its influence was weaker than the other dimensions, implying that attitude alone may not drive consistent safety performance without supportive structures and training. Behavioural Safety was dominated by operational practices particularly safety training and communication (Aderamo et al., 2024 and Jitwasinkul et al., 2011). This indicate that tangible learning opportunities, reinforcement mechanisms, and clear messaging are central to sustaining safe behaviours. The relatively weaker contributions of managerial indicators (such as management commitment and safety ownership) suggest that in this context, workers derive behavioural cues more strongly from established procedures, peer interactions, and communication systems rather than from supervisory directives. Situational Safety emerged as the strongest dimension, with safety rule compliance showing the highest loading (Pilbeam et al., 2016). This finding reinforces the importance of environmental control, regulatory adherence, and structural conditions as the foundation for safe operations. Consistent with our earlier AHP findings, elements such as technology/equipment, work environment, reporting systems, and job satisfaction played central roles, indicating that workers' behaviour is deeply influenced by the quality of their operational environment.

Collectively, the results reveal a layered safety ecosystem in which individual characteristics (education, job role), participatory involvement (OSH engagement), and structural conditions (rules, environment) interact to shape outcomes. Behavioural and situational mechanisms appear to mediate how workers translate knowledge, training, and organisational systems into safe practices (Kao et al., 2019). This suggests that interventions targeting safety culture must simultaneously strengthen procedural clarity, environmental support, communication channels, and continuous skill development. Relying solely on attitudinal or motivational programmes is unlikely to produce sustained improvements unless accompanied by operational and structural reinforcement (Breckenridge et al., 2019 and McCombs, 1984). The study provides several actionable insights for industry practitioners. First, continuous investment in structured and high-quality training is crucial for maintaining behavioural safety. Second, enhancing situational factors such as reporting systems, equipment reliability, and environmental control should remain a priority, as these form the backbone of safe operations. Third, encouraging OSH participation at all organisational levels can promote shared safety leadership and collective accountability. These implications underscore the need for integrated, multilevel safety interventions rather than single-focus programmes.

Despite its strengths, this study has several limitations. First, the cross-sectional design restricts causal interpretation; longitudinal studies are needed to track changes in psychological, behavioural, and situational safety over time. Second, reliance on self-reported data may introduce social desirability and recall bias, potentially inflating positive responses. Third, while the SEM model exhibited strong reliability, several managerial indicators showed weak or non-significant loadings, suggesting that additional or refined items may be necessary to more accurately capture supervisory influence. Fourth, although the sample spans multiple sectors, it may not fully represent smaller industries or micro-enterprises, limiting generalisability. Finally, the model does not incorporate leadership style, safety climate or cultural norms as moderating variables, which may play critical roles in shaping safety outcomes.

4.5.5 Conclusion

This study provides a robust and empirically validated higher-order framework of safety culture by integrating psychological, behavioural, and situational dimensions with individual and organisational predictors of safety outcomes. The findings highlight that education, occupational role, and OSH involvement play pivotal roles in shaping safety performance, while behavioural and situational mechanisms form the structural core of a resilient safety system. By advancing beyond prioritisation toward full structural validation, this work offers a clearer understanding of how attitudes, skills, environmental conditions, and participation interact to drive workplace safety. The integrated model presented here delivers actionable insight for designing targeted, multi-layered safety interventions and strengthens the evidence base for improving safety culture across high-risk industries.

4.6 Aim 5: Design and Development of the BOSCA Mobile Application Interface: A Behaviourally Informed Digital Framework for Safety Culture Transformation [8]

Occupational safety remains a critical concern in high-risk industries such as oil and gas, where human behaviour and organisational culture profoundly influence accident prevention and operational resilience (Egila et al., 2025 and Aderamo et al., 2024). Despite decades of investment in engineering controls and safety management systems, behavioural and cultural dimensions of safety continue to lag behind, often emerging as root causes in major industrial incidents (Goh et al., 2010 and Hofmann et al., 2017). Conventional safety training and compliance mechanisms typically delivered through audits, briefings, and paper-based reporting struggle to sustain worker engagement or translate safety awareness into consistent safe practices (Zahid et al., 2025). This gap underscores the pressing need for adaptive, behaviourally informed digital interventions capable of driving continuous participation and reinforcing safety values at all organisational levels.

While numerous digital safety tools have been developed globally, most existing systems, including *iSafe Work*, *Safety+*, and *e-Safety Training*, focus primarily on compliance tracking and hazard reporting rather than behavioural transformation (Denikhov et al., 2023 and Badea et al., 2024). These tools provide limited integration of motivational and cognitive constructs, resulting in short-term engagement and minimal long-term impact on safety culture. In contrast, the growing success of mobile health (mHealth) applications in influencing health-related behaviour suggests an untapped potential for similar frameworks in occupational safety (Istepnian, 2022). However, within Malaysia's oil and gas sector where complex operational hierarchies, communication gaps, and workforce diversity persist no comprehensive mobile-based intervention has yet been designed to embed behavioural theory directly into safety management practices (Hossain et al., 2025).

In this context, the present study introduces the Behavioural Occupational Safety Culture Application (BOSCA) a theory-driven, mobile-based intervention

[8] Hafiz Rahim, Nazri Che Dom, Rahmat Dapari, (2025). Design and Development of the BOSCA Mobile Application Interface: A Behaviourally Informed Digital Framework for Safety Culture Transformation *Scientific Report*. (Submitted: Nov 2025)

developed to enhance safety culture through behavioural engagement, motivation, and skill reinforcement. Building upon prior empirical findings from the study on stakeholder safety-culture priorities in Malaysia's oil and gas industry (Rahim et al., 2025), BOSCA was designed to translate those behavioural determinants into a digital ecosystem that promotes proactive safety participation. The system architecture integrates behavioural-change theory with user-centred design principles, creating an interactive platform that merges learning, reporting, and recognition into a cohesive behavioural feedback loop. The objective of this study is to design, develop, and validate the BOSCA mobile application interface and system architecture as a functional model for digital safety transformation. Specifically, the study aims to (i) operationalise behavioural constructs such as motivation and communication into interactive digital modules, (ii) establish a secure, multi-layered architecture for continuous monitoring and feedback, and (iii) evaluate the system's usability, functionality, and behavioural alignment. By merging behavioural science with digital innovation, BOSCA represents a new paradigm for strengthening safety culture in Malaysia's oil and gas sector transitioning from reactive compliance monitoring toward proactive, data-driven behavioural engagement.

4.6.1 Conceptual Framework of the Intervention

The conceptual framework of the BOSCA intervention (Figure 4.7) illustrates the theoretical underpinnings linking *motivation*, *behavioural skills*, *moderating factors*, and *health outcomes*. Grounded in the principles of behaviour-change theory, the model emphasises that motivation and behavioural competence are precursors to sustainable safety culture transformation. Moderating factors such as leadership commitment, communication, and reward systems shape these behavioural outcomes, which in turn influence the overall health and safety performance within oil and gas organisations. This conceptual framework served as the theoretical blueprint for the design and digital translation of the BOSCA system architecture. Each construct within the framework; motivation, behavioural skills, moderating factors and health outcomes was systematically operationalised into functional modules within the mobile application. Motivational elements were embedded through gamified reward systems and real-time feedback notifications; behavioural skills were translated into interactive training and competency assessment features; moderating factors such as leadership engagement and communication flow were integrated through managerial dashboards and alert systems; while health outcomes were represented as measurable performance indicators within the user analytics layer. This theoretical-to-digital alignment ensured that every component of BOSCA was grounded in behavioural science and organisational safety principles, providing a structured pathway from conceptual understanding to practical implementation. The resulting multi-layered architecture thus embodies the behavioural mechanisms illustrated in Figure 4.7, enabling dynamic feedback loops and continuous monitoring that drive progressive improvement in safety culture across the oil and gas sector.

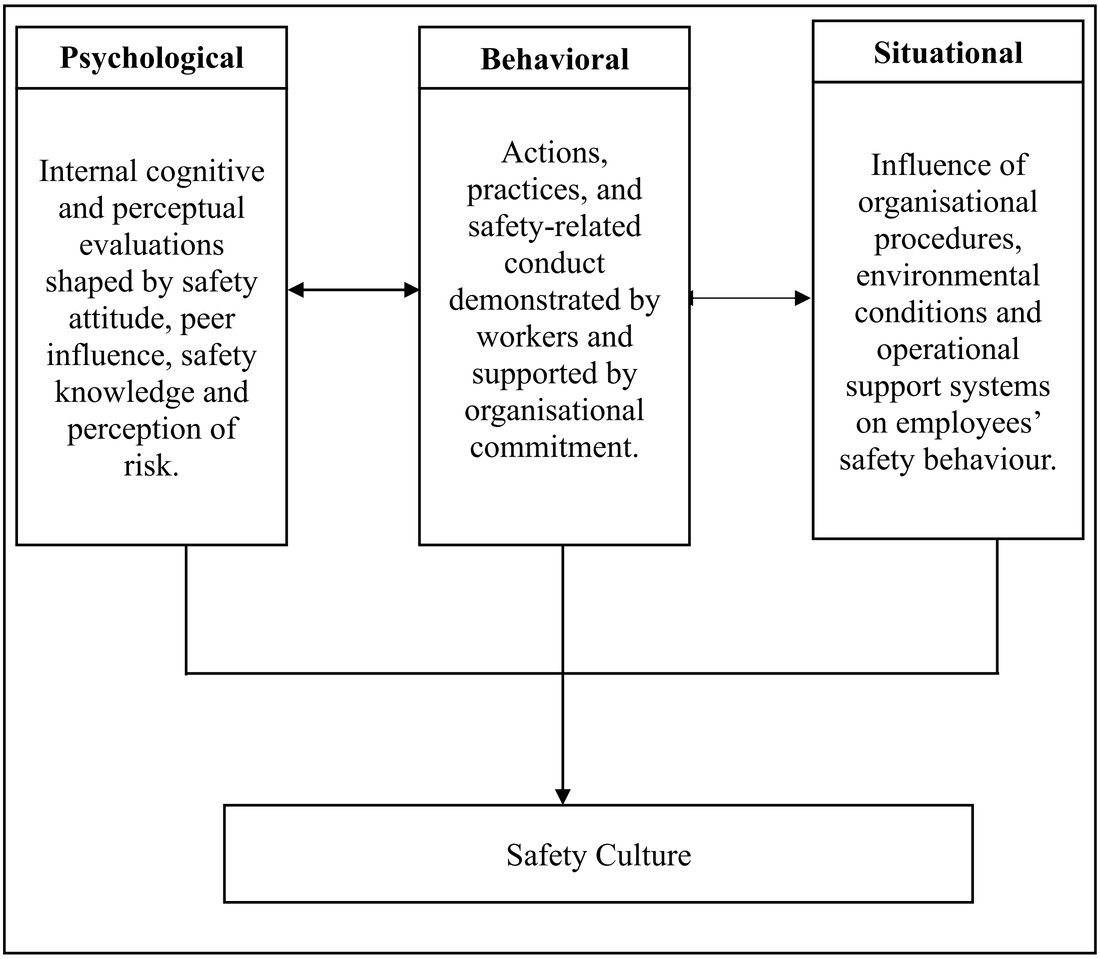

Figure 4.7 Conceptual Framework of the Intervention Model. Illustrating the Relationship Between Motivation, Behavioural Skills, Moderating Factors and Health Outcomes for Enhancing Safety Culture in the Oil and Gas Industry.

4.6.2 System Architecture and Functional Layers

The overall BOSCA system architecture (Figure 4.8) was designed as a multi-layered digital ecosystem that integrates behavioural, managerial and data-driven components to promote proactive safety culture management in the oil and gas industry. The architecture comprises four interdependent layers; Application, Control, Security & Integration and Data Storage each serving a distinct yet complementary role in ensuring seamless interaction between users and the backend infrastructure. Together, these layers form a robust system that allows continuous data exchange, real-time feedback, and secure information processing essential for high-risk industrial environments.

At the top of the hierarchy, the Application Layer represents the user-facing interface through which employees and managers interact with the BOSCA mobile app. It contains six core interactive modules; *Audit*, *Training*, *Reward Recognition*, *Incident Reporting*, *Competency*, and *Communication Alerts* that operationalise behavioural and organisational functions. The *Audit* module enables digital inspection and compliance tracking; the *Training* and *Competency* modules deliver micro-learning sessions and skill assessments; the *Incident Reporting* feature allows rapid documentation of hazards and near misses; the *Reward Recognition* module reinforces positive behaviour through a gamified point-and-badge system; and the *Communication Alerts* function provides real-time notifications, fostering situational awareness. These modules collectively enhance user engagement and ensure that behavioural data are continuously captured and channelled into the control system for further analysis. Beneath this lies the Control Layer, which acts as the central processing unit of the BOSCA architecture. It consists of the *Module Orchestrator*, *Incident Processor*, *Training Manager*, and *Audit Trail Manager*, each responsible for managing workflows, validating user input, and coordinating real-time operations between modules. This layer governs the logic of automated responses for instance, issuing reminders for pending training, escalating hazard reports, or updating user scores based on behavioural performance. Through continuous synchronization with the backend server, the control layer ensures the accuracy, consistency, and timeliness of data processing, effectively linking user actions to system-wide safety performance indicators.

The Security & Integration Layer provides a secure framework for data transmission and access control across the BOSCA platform. Built upon OAuth 2.0-

based authentication and Role-Based Access Control (RBAC), this layer verifies user identity, defines access privileges, and safeguards sensitive information through end-to-end encryption. Additionally, an integrated *Audit Trail* mechanism records all user activities and system transactions, ensuring transparency, traceability, and compliance with organisational data-governance policies. This approach parallels international best practices in secure digital health and industrial monitoring systems, where data integrity and confidentiality are paramount. At the base of the architecture, the Data Storage Layer serves as the central repository for encrypted datasets, including user profiles, incident logs, training records, audit outcomes, and competency metrics. This layer employs structured database management with timestamping to preserve the integrity and provenance of each record. By maintaining separation between identifiable information and behavioural data, the architecture minimises privacy risks while supporting advanced analytics for safety performance evaluation. Collectively, these four layers form an integrated architecture that transforms behavioural safety theory into a functional, data-driven platform. The design not only facilitates secure, real-time communication between users and the backend framework but also enables continuous learning, monitoring, and feedback loops essential for cultivating a resilient safety culture within the oil and gas industry.

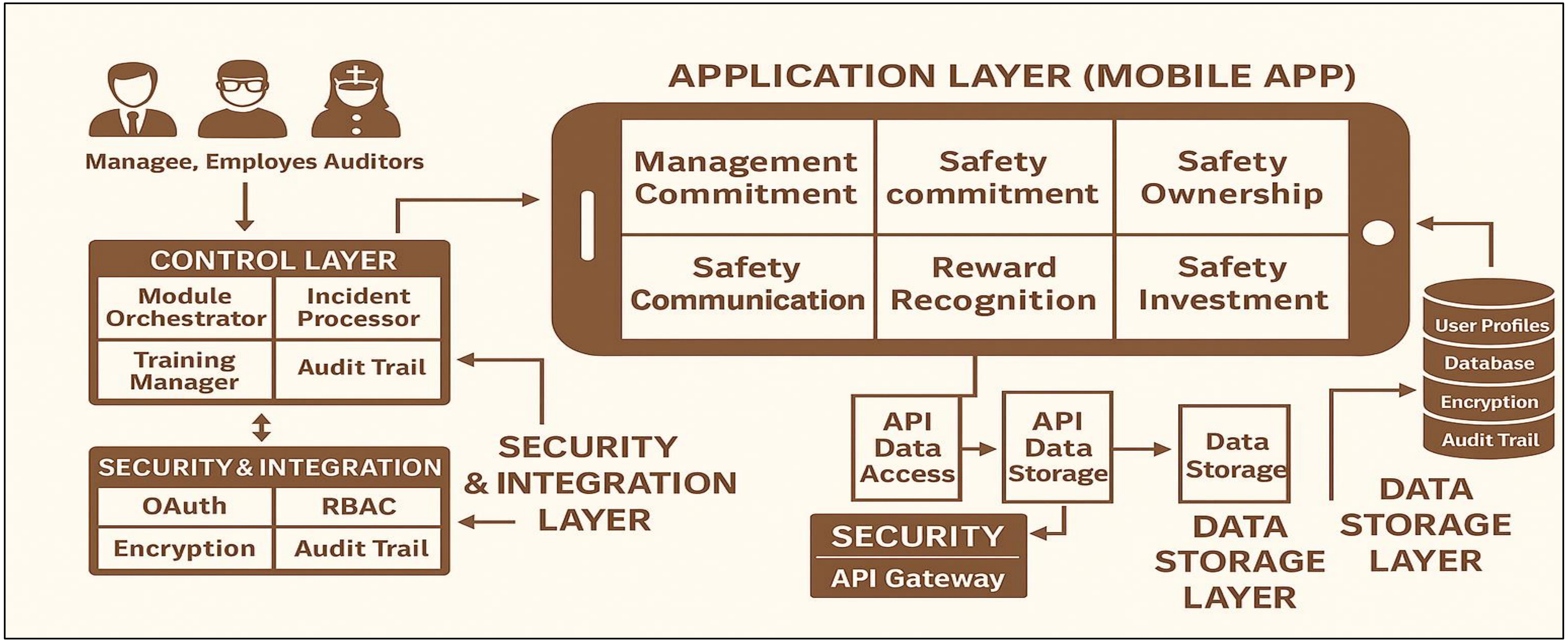

Figure 4.8 System Architecture of the Mobile Safety Management Application, Illustrating the Interaction between Different Functional Layers. The Application Layer (Mobile App) Comprises Core Modules. These Modules Interface with the Control Layer (Module Orchestrator, Incident Processor, Training Manager, Audit Trail), the Security & Integration Layer (OAuth, RBAC, Encryption, Audit Trail), and the Data Storage Layer (User Profiles, Database, Encryption, Audit Trail). The Framework Ensures Secure Data Flow, User Role Management, And Continuous Monitoring to Enhance Safety Culture Within the Organisation.

4.6.3 Intervention Outcomes and Performance Objectives

Table 4.14 presents the matrix of intervention outcomes, performance and change objectives developed through the Phase 1 needs assessment. Each objective corresponds to specific requirements, expected behavioural changes, and anticipated outcomes aimed at improving safety culture. For instance, strengthening management commitment was linked to enhancing accountability, improving communication, and demonstrating visible leadership. Likewise, improving safety training and communication was intended to enhance knowledge retention and information flow, while the introduction of a digital reward system promoted positive reinforcement and safety ownership.

Table 4.14
Intervention Outcomes, Performance and Change Objectives Matrix Based on the Needs Assessment in Phase 1

Objectives	Requirements	Behaviour	Constraints	Outcomes
Strengthening Management Commitment	• Develop leadership-driven safety initiatives • Enhance accountability and communication between managers and staff	Demonstrate visible leadership in safety programs and respond to feedback proactively	Limited time commitment from management Hierarchical decision-making	Improved safety leadership and communication culture
Enhancing Safety Commitment	• Establish shared safety values and responsibilities • Encourage consistent participation in safety activities	Participate actively in reporting, safety talks, and audits	Low motivation and inconsistent engagement	Increased safety awareness and compliance
Promoting Safety Ownership	• Encourage employees to take responsibility for workplace safety • Create self-reporting and monitoring mechanisms	Report hazards and unsafe acts promptly	Fear of blame or repercussions	Improved accountability and proactive reporting behaviour
Improving Safety Training	• Provide accessible, interactive digital learning content • Conduct periodic refresher modules	Complete in-app safety training and assessments	Connectivity limitations Time availability	Enhanced knowledge retention and training participation
Strengthening Safety Communication	• Develop a real-time communication channel for safety alerts and notifications	Share information promptly and provide peer feedback via the app	Technological literacy Information overload	Faster information dissemination and improved situational awareness
Reward and Recognition System	• Define measurable safety performance indicators • Implement digital recognition and reward badges	Engage consistently in safe practices and mentoring peers	Budget constraints Possible bias in recognition	Reinforced positive safety behaviour and motivation
Supporting Safety Investment	• Allocate resources for safety innovation and improvement programs • Track safety investments digitally	Record and update investment activities through the app	Limited organisational budget Bureaucratic approval delays	Increased transparency in safety investment tracking

Objectives	Requirements	Behaviour	Constraints	Outcomes
Developing Safety Competency	• Create competency-based safety assessments and matrix • Link training outcomes to performance metrics	Demonstrate skills improvement via assessment results	Variability in user participation Training fatigue	Improved skill competency and continuous learning culture

4.6.4 Wireframe Design and Module Integration

Figure 4.9 presents the wireframe designs that guided the layout and workflow of BOSCA. The initial schematic was iteratively refined to ensure logical transitions between screens, minimal cognitive load, and visual clarity. The wireframe delineates eight primary interfaces: *Login*, *Dashboard*, *Training*, *Audits*, *Rewards*, *Alerts*, *Enhancement*, and *Profile Management*. The dashboard serves as a central hub linking all modules, while the profile interface summarises individual achievements, completed audits, and training scores. These components collectively reinforce behavioural engagement through continuous feedback loops.

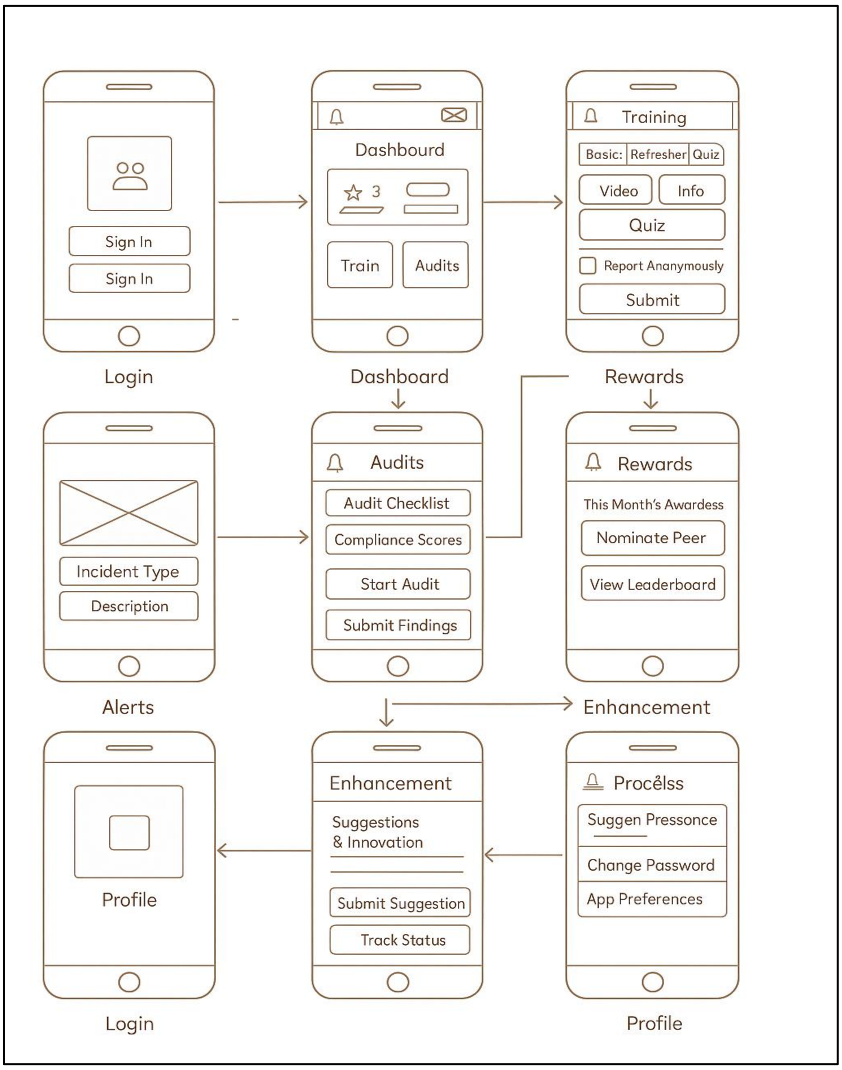

Figure 4.9 Wireframe Designs for the Behavioural Occupational Safety Culture Application (BOSCA). Note: The Wireframe Illustrates the Functional Flow of BOSCA Modules, Including *Login, Dashboard, Training, Audits, Rewards, Alerts, Enhancement,* and *Profile Management.* Each module was designed to enhance behavioural safety engagement and compliance among oil and gas industry employees.

4.6.5 Control-Layer Algorithm Flow

The control-layer algorithmic flow (Figure 4.10) comprises three integrated processes that translate user activity into automated system responses. The data collection and validation algorithm (Figure 4.10A) captures behavioural safety inputs such as audits, incidents, and training records and verifies their completeness and accuracy before database storage. The automated feedback and notification engine (Figure 4.10B) analyses validated data to generate real-time alerts and motivational messages, reinforcing user engagement and timely response to safety tasks. The scheduling algorithm (Figure 4.10C) issues reminders for upcoming audits, training, and reporting deadlines, maintaining consistent participation across users. Together, these processes establish a continuous feedback loop in which behavioural data inform training, communication, and recognition systems, fostering adaptive learning and accountability throughout all organisational levels.

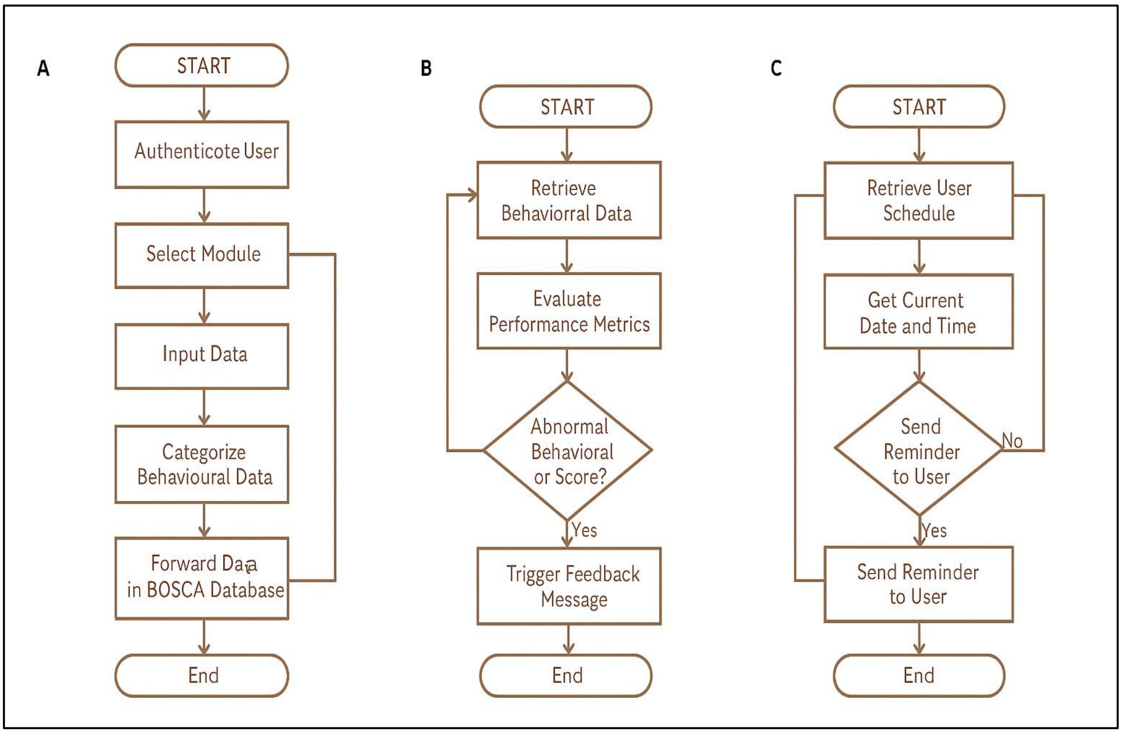

Figure 4.10 Flowcharts of Algorithms Implemented in the Control Layer of the BOSCA Application, where (A) Presents the Data Collection and Validation Process for Behavioural Safety Input; (B) Describes the Automated Feedback and Notification Engine that Reinforces User Engagement; And (C) Represents the Scheduling Algorithm that Notifies Users of Upcoming Training, Audit, or Reporting Deadlines.

4.6.6 BOSCA Mobile Application Interface

The BOSCA mobile application interface (Figure 4.11) integrates six core modules: Audit, Training, Reward Recognition, Incident Reporting, Competency, and Communication Alerts to support continuous behavioural engagement and organisational safety monitoring. The Audit module enables digital inspections and automated scoring; the Training and Competency modules deliver interactive learning and assess skill proficiency; the Incident Reporting module streamlines hazard and near-miss submissions with real-time notifications; the Reward Recognition module reinforces motivation through digital badges and points; and the Communication Alerts module ensures timely dissemination of safety messages and updates. Collectively, these modules provide a user-friendly, interactive platform that transforms behavioural theory into practice, fostering proactive participation, accountability, and continuous improvement in workplace safety culture.

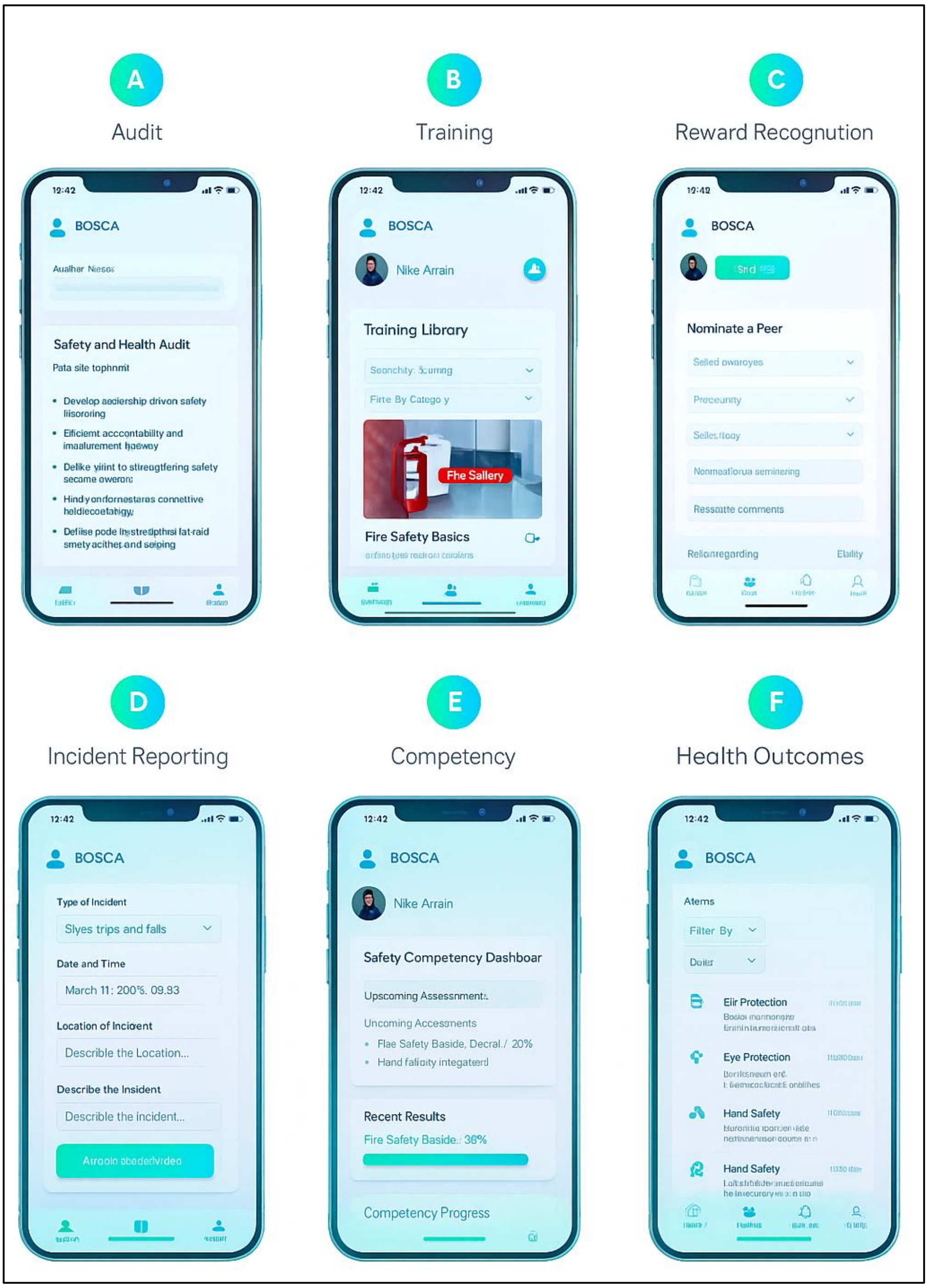

Figure 4.11 BOSCA Mobile Application Interface Showcasing Six Core Modules: (A) Audit, (B) Training, (C) Reward Recognition, (D) Incident Reporting, (E) Competency, and (F) Communication Alerts — Designed to Promote Proactive Safety Management, Competency Tracking and Real-Time Engagement Within the Oil and Gas Industry.

4.6.7 Discussion

This study introduces the Behavioural Occupational Safety Culture Application (BOSCA), a digitally integrated intervention designed to enhance safety culture in the oil and gas industry through a theory-driven behavioural approach. The system combines behavioural science, digital innovation, and organisational learning into a cohesive framework that supports motivation, skill development, feedback, and accountability. The findings demonstrate that behavioural-change theory can be successfully operationalised through mobile technology, offering a structured pathway from conceptual understanding to practical implementation of safety culture enhancement (Nævestad et al., 2018, Rahim et al., 2023, and Vankov, 2021). Previous mobile interventions in occupational and public health contexts have largely focused on information dissemination or compliance monitoring, with limited integration of behavioural constructs (Buckingham et al., 2019, Melzner and Park et al., 2023). Early digital safety tools such as e-Safety Training, iSafe Work, and Safety+ were primarily designed for digital checklists, incident reporting, or compliance documentation, often neglecting intrinsic motivational factors that sustain behavioural change (Par et al., 2023 and Aderamo et al., 2024). In contrast, BOSCA was developed to address this critical gap by embedding the motivational, cognitive, and contextual components of behavioural theory directly within its system architecture (Rahim et al., 2023). Similar to the mHealth intervention model, which employed intervention mapping to develop a hypertension self-management app, BOSCA aligns each digital function with the core constructs of the Information–Motivation–Behavioural Skills (IMB) framework. This theoretical grounding ensures that BOSCA not only delivers safety content but also facilitates active behavioural engagement through continuous feedback, reinforcement, and performance analytics.

The BOSCA system architecture’s four interconnected layers; Application, Control, Security & Integration, and Data Storage represent a major advancement in digital safety management. This multi-layered architecture enables seamless communication between users and the backend while maintaining high levels of data integrity and privacy (Farhoui et al., 2024 and Joseph, 2023). The control-layer algorithm, with its automated feedback, notification, and scheduling mechanisms, transforms user activity into adaptive system responses that sustain engagement and accountability (Naseri et al., 2022). This continuous feedback loop parallels the real-time data validation and automated reinforcement systems used in validated health management applications but is uniquely adapted here for industrial safety operations. The architecture's modularity also facilitates scalability, allowing BOSCA to be tailored for different operational environments without compromising functionality or security (Repetto et al., 2021). The interface and wireframe designs further demonstrate BOSCA's emphasis on usability and behavioural reinforcement. The integration of six core modules; Audit, Training, Reward Recognition, Incident Reporting, Competency, and Communication Alerts creates a user-friendly ecosystem that enables two-way communication between employees and management. By combining automated training, hazard reporting, and gamified recognition features, BOSCA promotes consistent behavioural participation while cultivating a shared sense of ownership in workplace safety. Such features address one of the key limitations identified in previous digital safety systems: low long-term engagement and poor data feedback mechanisms (Hottey et al., 2012). The use of real-time notifications and reward-based reinforcement enhances motivation, mirroring findings from mobile health studies where gamified engagement significantly improves adherence and task completion rates (Vergara et al., 2025 and Liao et al., 2025).

In comparison with earlier digital interventions, BOSCA represents a paradigm shift from passive compliance monitoring to proactive behavioural transformation. Previous applications in industrial safety, including those developed for construction and manufacturing sectors, primarily served as reporting tools with limited behavioural analytics (Aderamo et al., 2024 and Pereira et al., 2020). BOSCA, however, integrates data-driven feedback and competency-based reinforcement into its control logic, allowing organisations to monitor progress, identify gaps, and adapt training based on real-time performance metrics. This integration of feedback, analytics, and motivational psychology reflects an evolution toward personalised, adaptive digital safety systems aligned with Industry 4.0 objectives. Beyond technical innovation, BOSCA contributes conceptually to the evolution of safety culture theory by demonstrating how motivation and behavioural skills can be continuously reinforced through digital feedback ecosystems. The dynamic interaction between the application's modules replicates the cyclical nature of behavioural change where performance outcomes feed back into motivation and skill development. By converting these theoretical constructs into functional digital processes, BOSCA advances the practical implementation of behavioural safety interventions at scale. Overall, this study highlights the potential of behaviourally informed digital technologies to transform occupational safety management. BOSCA demonstrates that when behavioural theory, feedback algorithms, and user-centred design converge within a secure mobile platform, the result is a sustainable system that not only monitors safety compliance but actively cultivates a culture of continuous improvement. Future research should evaluate the system's usability, longitudinal engagement, and measurable impacts on incident rates and workforce attitudes toward safety. With appropriate validation and cross-sector adaptation, BOSCA could serve as a model for developing digital interventions that merge behavioural science with data analytics to achieve safer, more resilient.

4.6.8 Conclusion

This study demonstrates that the Behavioural Occupational Safety Culture Application (BOSCA) effectively translates behavioural-change theory into a functional, secure, and user-centred digital platform for improving safety culture in the oil and gas industry. By integrating motivational reinforcement, skill development, and adaptive feedback within a multi-layered architecture, BOSCA moves beyond traditional compliance tools toward a proactive, data-driven model of safety management. Its six interactive modules and control-layer algorithms create continuous learning and communication loops that sustain engagement, accountability, and organisational improvement. Compared with previous mobile safety and mHealth applications, BOSCA offers a more comprehensive, theory-grounded framework that bridges behavioural science and industrial practice. Future validation and field implementation will be essential to assess its long-term impact on behavioural performance, incident reduction, and workforce resilience, but its current design provides a strong foundation for advancing digital behavioural safety interventions across high-risk sectors.

4.7 Aim 6: Developing A Real-Time Behavioural Safety Culture (BOSCA) Using Progressive Web Applications (PWA) [9]

Safety culture is increasingly recognised as a fundamental component of risk management in the oil and gas industry (Rocha et al., 2024, AlNoaimi, 2021, Ehiaguina, 2020 and Ghapa et al., 2023). Despite various safety initiatives, the industry continues to report high rates of accidents and incidents (IOGP, 2024, Manikumar et al., 2024, and Mochtar, 2024). The complex and high-risk nature of operations in this sector necessitates a safety culture that not only shapes behaviours but also serves as a proactive measure against potential risks. Traditional safety management systems, which rely heavily on retrospective data analysis and manual documentation, have long served as the backbone of risk management. However, these conventional approaches often fall short in promptly identifying hazards and communicating risks, particularly in dynamic environments where timely responses are critical (Qiao et al., 2022, Afzal et al., 2021 and Darveau, 2017). Their reactive nature, with a primary focus on compliance, limits their ability to foster a proactive and prevention-oriented safety culture. This reliance on lagging indicators and post-incident evaluations can delay corrective actions, leaving organisations exposed to unforeseen safety threats (Dechy et a., 2023 and Mehrizi et al., 2022).

As the oil and gas industry faces increasingly complex operational challenges, there is a pressing need for innovative solutions that bridge the gap between reactive systems and proactive safety management. Such approaches must support real-time decision-making and enhance organisational adaptability in mitigating risks (Aderano et al., 2024 and Zakizadeh, 2024). Recent technological advancements offer promising opportunities to transform safety management. Tools such as real-time data collection, automated analytics, and digital feedback mechanisms enable more immediate and data-driven safety interventions (Wanasinghe et al., 2021 and Oxyandi, 2024). Nevertheless, existing safety frameworks often fail to integrate these technologies into a cohesive structure that systematically addresses behavioural and cultural dimensions of safety (Guo, 2023 and Zhou, 2013).

[9]Hafiz Rahim, Rahmat Dapari, Nazri Che Dom, Mohd Iqbal Mohd Noor (2024). Developing a Real-Time Behavioural Safety Culture Framework (BOSCA) Using Progressive Web Applications (PWA). *Malaysian Journal of Medicine and Health Sciences*. Article ID: MJMHS-2024-2158.R1 (Accepted: 8 Aug 2025)

This critical gap underscores the need for a comprehensive digital framework tailored to the unique operational context of the oil and gas industry. To address this gap, the following research question was formulated: How can a Progressive Web Application (PWA) be systematically developed to incorporate behavioural safety culture elements for improving proactive safety management in the oil and gas industry?

This study introduces the development of the Behavioural Occupational Safety Culture Application (BOSCA), a digital framework designed to address the limitations of conventional safety systems. BOSCA leverages state-of-the-art technologies to enable continuous monitoring and analysis of safety behaviours, facilitating real-time feedback and timely interventions (Van Nunen, 2018, Nnaji, 2020 and Odu, 2023). By providing instant insights to management, the system helps mitigate safety risks before they escalate (Kopetz, 2022 and Carbonari, 2011). The primary aim of this study is to develop a comprehensive and user-centric safety management application that integrates critical behavioural elements into a scalable PWA. Through intuitive interfaces, interactive data visualisation, and feedback mechanisms, BOSCA seeks to enhance safety practices in high-risk industrial environments. This approach represents a paradigm shift toward a more proactive, data-driven, and behaviourally anchored model of safety management in the oil and gas sector.

4.7.1 Development of A Real-Time Behavioural Safety Culture Application

The results of the BOSCA framework showcase a cohesive set of interfaces, each meticulously designed to address specific facets of safety culture within the oil and gas industry. Figure 4.12 illustrates the BOSCA key interfaces, designed to enhance safety culture in the oil and gas industry. The figure presents six main interfaces: audit, training, reward recognition, incident reporting, competency, and communication alerts. Each interface plays a distinct role, from conducting and reviewing safety audits to providing interactive training, recognising safe behaviours, streamlining incident reporting, assessing employee competencies, and delivering real-time safety alerts. Together, these interfaces create a comprehensive and user-friendly platform, reinforcing proactive engagement and effective communication to promote a strong safety culture.

The audit interface, as shown in Figure 4.12A, is structured to facilitate detailed and systematic safety audits within the application. It includes modules for conducting audits and generating reports, enabling users to thoroughly review audit scores and identify potential areas for improvement. The intuitive design allows users to easily log non-conformances and document their findings. This proactive identification of safety issues through ongoing monitoring strengthens organisational safety culture by promoting consistent and rigorous audit practices. The training interface, depicted in Figure 4.12B, aims to enhance employees' safety competencies by providing access to a wide range of training materials relevant to the oil and gas industry. Users can engage in interactive training sessions that cover various safety topics, thereby fostering continuous learning. The structured approach allows users to track their progress across different training modules, emphasizing the importance of skill development. This feature is essential for upholding high safety standards and equipping employees with the knowledge necessary to perform their duties safely.

The reward recognition interface, illustrated in 4.12C, incentivises safe behaviours by acknowledging and rewarding employees who exhibit a strong commitment to safety. Managers can nominate and recognise individuals or teams for their safety contributions through a system for tracking and managing rewards. By promoting a culture of recognition, this feature aligns individual motivations with organisational safety objectives, encouraging employees to prioritise safety in their daily operations. The incident reporting interface, as shown in Figure 4.12D, provides users with a streamlined process for reporting safety incidents. It includes fields to capture detailed information such as the type of incident, location, time, description, image evidence, and severity. The user-friendly design facilitates prompt and accurate incident reporting, which is crucial for timely investigations and the implementation of preventive measures. This interface promotes a transparent safety culture by ensuring that incidents are managed efficiently and transparently.

The competency interface, depicted in Figure 4.12E, focuses on assessing and monitoring employees' safety competencies. It features tools for evaluating safety skills, tracking certifications, and identifying areas for improvement. Users can view their competency levels across various safety areas, providing them with a clear understanding of their strengths and potential growth opportunities. This feature reinforces the importance of continuous skill development and ensures that employees maintain the necessary competencies for their roles. The communication alerts interface, shown in Figure 4.12F, enhances real-time communication regarding safety-related matters. It enables users to receive alerts about critical safety information, such as hazards, policy updates, or emergency notifications. Alerts are delivered promptly to ensure that all employees are informed and can respond appropriately. This feature supports a proactive safety culture by ensuring the swift and effective communication of essential safety information across the organisation. The BOSCA framework effectively integrates these interfaces to provide a comprehensive platform for promoting and sustaining a strong safety culture. Each interface contributes to reinforcing a proactive and transparent approach to safety management, empowering users to engage actively in safety practices within the organisation.

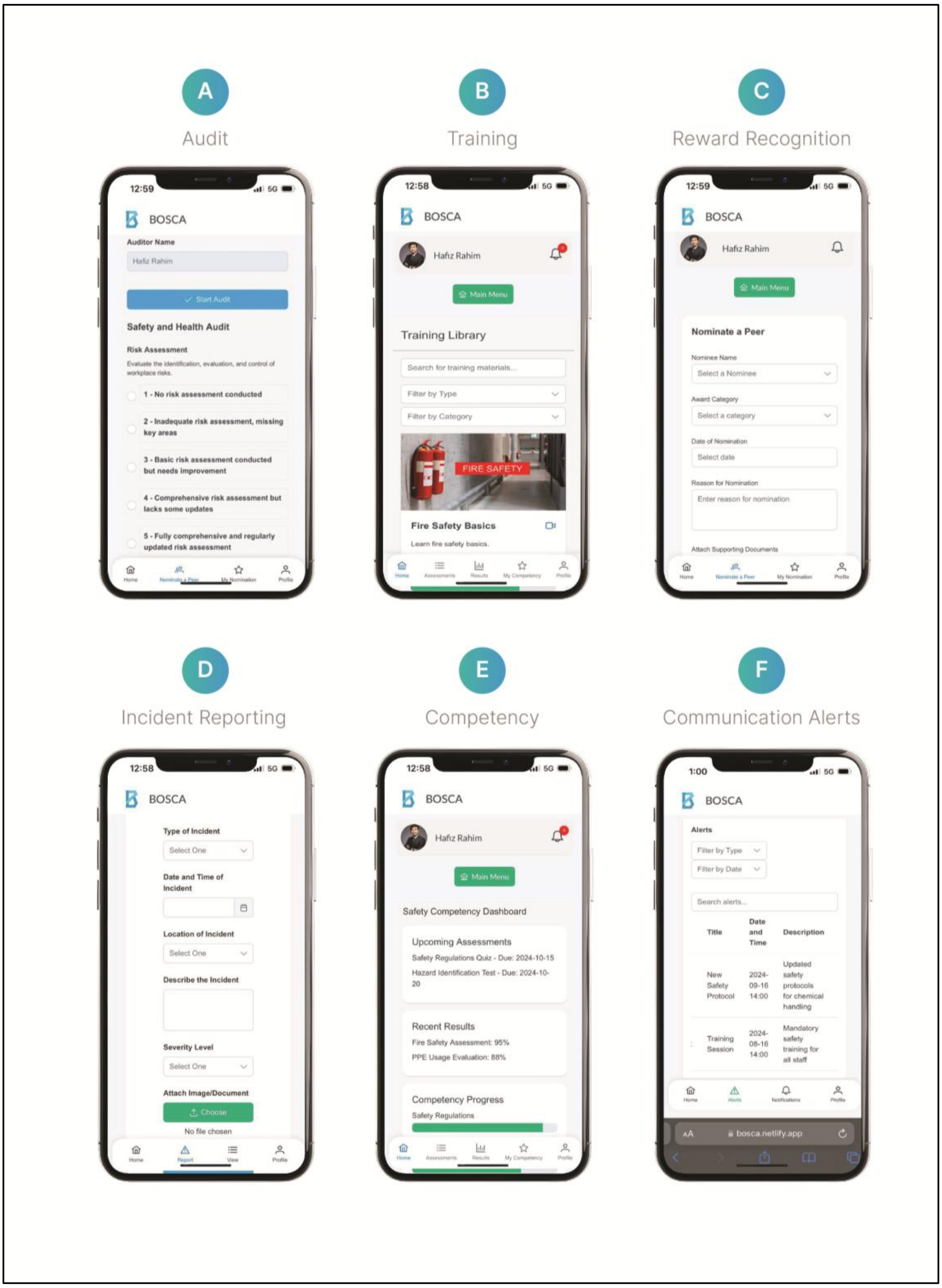

Figure 4.12 Key Interfaces of the Behavioural Occupational Safety Culture Application (BOSCA), Designed to Enhance Safety Culture in the Oil and Gas Industry. The Figure Presents Six Main Interfaces: (A) Audit, (B) Training, (C) Reward Recognition, (D) Incident Reporting, (E) Competency, and (F) Communication Alerts. Each Interface Plays a Distinct Role, from Conducting and Reviewing Safety Audits to Providing Interactive Training, Recognising Safe Behaviours, Streamlining Incident Reporting, Assessing Employee Competencies and Delivering Real-Time Safety Alerts.

The visualization manager within the BOSCA framework serves as the central component that consolidates and presents safety data in a cohesive and meaningful format, acting as an interactive hub for managing the four key elements: reward recognition, safety competency, safety communication, and safety investment (Figure 4.13). Its primary function is to transform raw data into actionable insights through various visualization techniques such as dashboards, graphs, and charts, providing real-time updates that allow safety managers to monitor trends in reported incidents, track employee training completion rates, and oversee the distribution of safety rewards. This interactive and centralized visualization approach facilitates seamless monitoring of key safety performance indicators (KPIs), enabling stakeholders to assess the effectiveness of different safety initiatives and implement targeted interventions based on clear patterns and areas needing improvement. The visualization manager supports real-time decision-making and fosters transparency by making critical information accessible to relevant stakeholders, empowering them to generate customised reports and drill down into specific data details. Additionally, it plays a vital role in long-term strategic planning by identifying trends and correlations that guide future safety investments and policy changes, thereby promoting a data-driven and proactive approach to safety management. By synthesizing and presenting critical information effectively, the visualization manager reinforces continuous improvement, accountability, and the proactive management of safety culture within the organisation.

The reward recognition component within the BOSCA framework is designed to incentivise and acknowledge safe behaviours and contributions to safety culture within the organisation (Figure 4.13). This component enables managers to systematically track and reward individuals or teams who demonstrate a strong commitment to safety, aligning individual motivations with the organisation's safety objectives. The system allows managers to nominate employees for their proactive safety actions, document their contributions, and recognise them through a structured rewards program. By offering a transparent and systematic approach to recognition, this component fosters a culture of appreciation where safe behaviours are consistently encouraged and reinforced. The rewards, which can be both tangible and intangible, are strategically designed to motivate employees to adhere to safety protocols and go beyond compliance. Moreover, the reward recognition component includes features for tracking and managing the rewards distributed, providing a clear record of the organisation's commitment to reinforcing positive safety practices. This structured approach not only enhances individual and team engagement but also contributes to a collective focus on upholding high safety standards throughout the organisation. Through this alignment of recognition with safety goals, the reward recognition component plays a crucial role in promoting a proactive and safety-conscious work environment.

The safety competency component within the BOSCA framework is focused on assessing, monitoring, and enhancing the safety-related skills and qualifications of employees within the organisation. This component is designed to provide tools for evaluating employee competencies through periodic assessments and tracking of safety certifications. By maintaining a centralised record of competencies, the system ensures that employees are equipped with the necessary knowledge and skills to perform their roles safely, in alignment with the organisation's safety standards. The safety competency interface offers features that allow users to view their competency levels across various safety domains, identify areas requiring improvement, and access additional training resources if needed. This continuous monitoring supports a dynamic and adaptive safety culture, where skill gaps can be promptly identified and addressed to minimize risks. Moreover, it enables management to make informed decisions regarding workforce readiness and the allocation of training resources. By promoting a culture of continuous learning and development, the safety competency component reinforces the importance of staying up-to-date with industry best practices and safety protocols, ultimately contributing to a safer and more competent workforce. Through this structured and proactive approach, the BOSCA framework not only ensures compliance with safety standards but also fosters a culture of ongoing improvement and preparedness in high-risk environments (Figure 4.13).

The safety investment component within the BOSCA framework plays a crucial role in supporting strategic planning and resource allocation for safety initiatives within the organisation. This component is designed to provide insights into the effectiveness of safety investments by tracking and evaluating expenditures related to safety programs, equipment, training, and other critical areas. By integrating financial data with safety performance indicators, the safety investment component allows management to make informed, data-driven decisions on where to allocate resources to achieve the greatest impact on overall safety performance. This feature helps identify the most effective safety initiatives and areas requiring additional investment, ensuring that resources are directed toward programs and measures that significantly enhance safety outcomes. It also enables organisations to assess the return on investment (ROI) for various safety measures, thereby optimising spending to align with safety goals and regulatory compliance. The component’s detailed analysis capabilities support ongoing evaluation and refinement of safety strategies, encouraging a proactive approach to improving safety culture through targeted investments. By promoting transparency and accountability in resource management, the safety investment component reinforces the organisation's commitment to prioritising safety and allocating the necessary resources to maintain high standards. This strategic focus not only helps organisations achieve their safety objectives but also fosters a culture where safety is viewed as a valuable and essential investment in the workforce’s well-being and operational resilience (Figure 4.13).

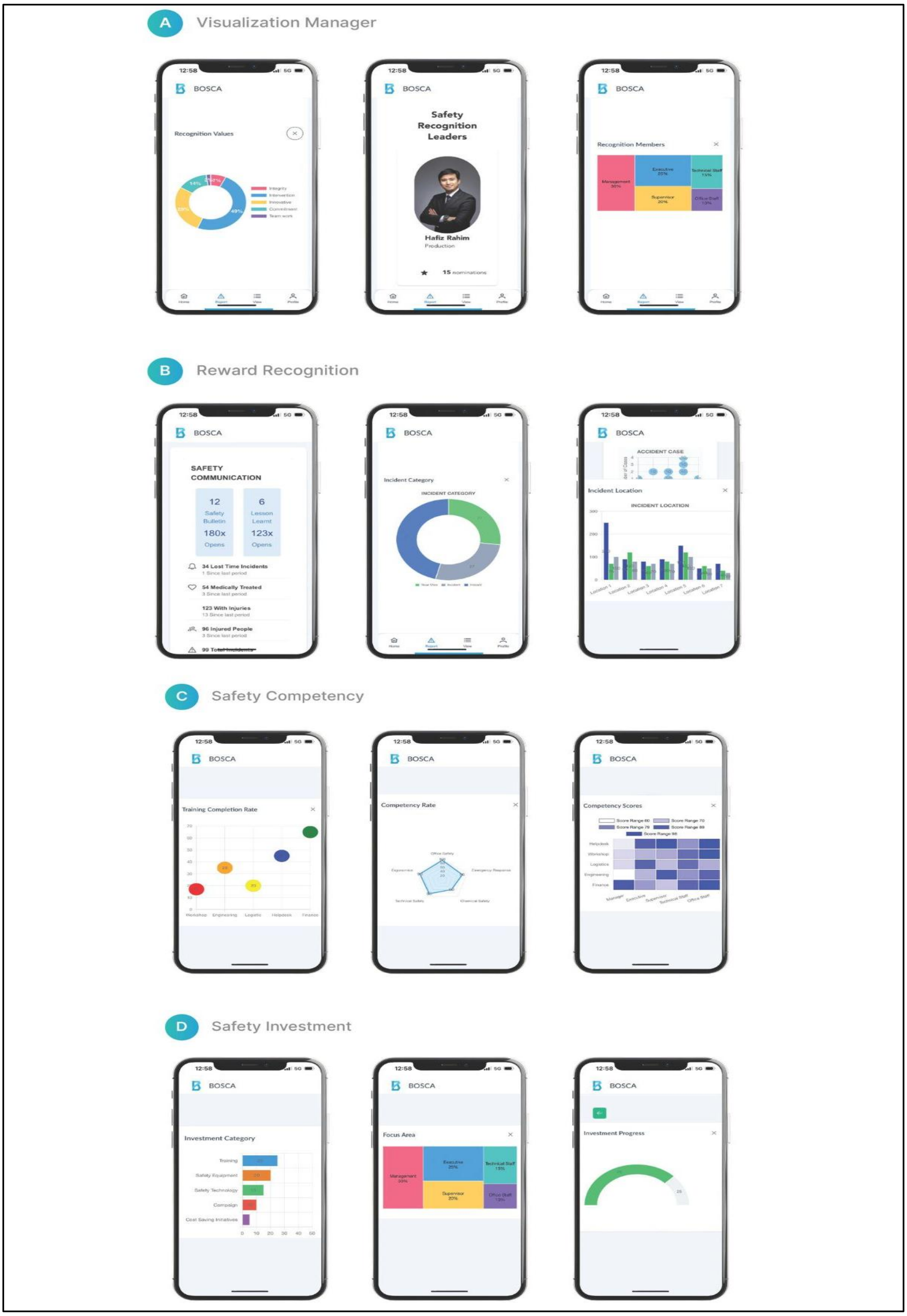

Figure 4.13 Key Elements Managed by the Visualization Manager within the Behavioural Occupational Safety Culture Application (BOSCA). This Figure Highlights Four Primary Components: (A) Visualization Manager; (B) Reward Recognition, (C) Safety Competency, and (D) Safety Investment.

4.7.2 Validation Scope

The BOSCA framework underwent internal validation during the development process, which included system-level testing and simulated user walkthroughs to verify the functionality, stability, and integration of its features. This testing ensured that modules such as hazard reporting, training access, and communication alerts performed reliably across different devices and user roles. External validation, including pilot deployment, real-world user interaction, and behavioural impact analysis, was not included within the scope of this development-focused manuscript. A separate validation study is currently in progress to evaluate the BOSCA application in actual operational settings and will be reported in future publications.

4.7.3 Discussion

Benefits of BOSCA framework: Our framework for real-time monitoring of behaviour and safety culture in the oil and gas industry integrates several critical methods to ensure comprehensive and accurate data capture. The framework systematically documents safety incidents and activities through electronic logs and manual reports, which are periodically reviewed to identify and analyse trends. It also leverages online surveys and mobile apps to gather employee perspectives on safety culture, collected at regular intervals (monthly or quarterly), providing qualitative insights into the effectiveness of safety programs. Additionally, the framework tracks training and compliance records to monitor participation in safety training and adherence to safety regulations, ensuring records are up-to-date and reflective of ongoing efforts. Continuous monitoring of health and safety metrics, coupled with periodic assessments, enables real-time evaluation of safety performance and ensures adherence to established standards.

A key component of our framework is the user interface design, which ensures that stakeholders can effectively access and interpret real-time data. The user interfaces are designed to be intuitive and accessible, featuring dashboards that display critical safety information clearly and organised. Key features include customisable views, real-time data updates, and visualizations such as graphs and heat maps to highlight trends and anomalies. Usability considerations such as simplicity of navigation, readability of data, and responsiveness across various devices and screen sizes are prioritised. The interface is developed with input from end-users to ensure it meets their needs and preferences, facilitating quick and accurate decision-making. Accessibility features, including adjustable font sizes and colour schemes, accommodate diverse user needs, ensuring that critical safety information is effectively communicated to all stakeholders. This user-centred design approach enhances the usability of the system, promoting efficient monitoring and proactive management of safety culture.

Practical implications and future work: It is important to note that while the current study focused on internal system development and validation, further research will assess BOSCA's usability, engagement levels, and behavioural outcomes through external validation in field conditions. The BOSCA application, by enabling real-time monitoring and feedback, addresses critical gaps in traditional safety systems, aligning with findings from prior studies on behaviour-based safety frameworks and technology-enabled safety systems (Otewole, 2024, Lal, 2022, and Pika, 2021). This capability allows organisations to address potential safety issues proactively, thereby reducing the risk of incidents and enhancing overall safety performance (Aderamo et al., 2024). The ability to provide instant feedback and actionable insights not only empowers managers to make informed decisions quickly but also fosters a more engaged and safety-conscious workforce (Nukhori et al., 2021). Furthermore, the framework's provide comprehensive approach, which includes data collection, processing, and visualization through an intuitive interface. This integration of advanced technology with traditional safety management approaches marks a significant shift towards more dynamic and responsive safety management in high-risk industries like oil and gas (Lee, 2019, Haouel, 2024, and Mahmuud et al.,2023). The implications of this framework extend beyond immediate safety improvements, contributing to the long-term sustainability of safety practices and the cultivation of a proactive safety culture.

Challenges and implementation considerations: However, implementing this framework is likely to encounter challenges, particularly in integrating with existing systems, ensuring data privacy, and managing the complexity of real-time data processing. Integration strategies involve developing robust APIs and compatibility solutions to facilitate seamless data exchange with legacy systems, ensuring a smooth transition and accessibility across platforms (Kommisetty, 2024, Borgogno, 2019, and Ponnusamy, 2023). Data privacy is addressed by implementing comprehensive security measures, including end-to-end encryption and access controls, to safeguard sensitive information (Anrera, 2024). Complexity management is handled by utilising scalable technologies such as cloud computing and distributed databases, along with adaptive algorithms capable of dynamically processing large volumes of real-time data, enabling timely and accurate decision-making (Vemulapalli, 2023, Kumari et al., 2018, and Mehmood, 2020).

Limitation and strength: One of the primary limitations of the study lies in the integration challenges associated with implementing the BOSCA within existing infrastructure in the oil and gas industry. The complexity of legacy systems may hinder the seamless integration of the BOSCA, requiring significant customisation and potentially increasing implementation costs and time. Another limitation is the potential resistance from end-users who are accustomed to traditional safety management practices. The shift to a real-time, behaviourally driven monitoring system might require extensive training and a change in mindset, which could pose challenges in adoption. Additionally, while the BOSCA is tailored for the oil and gas industry, its specific focus on this sector may limit its applicability and effectiveness in other industries without substantial modifications.

Despite these limitations, the study has several key strengths. The BOSCA represents a significant advancement in safety management by integrating real-time monitoring with a comprehensive behavioural framework, which is not commonly found in existing safety management systems. The inclusion of eight critical sub-elements, namely management commitment, safety commitment, safety ownership, safety training, safety communication, reward recognition, safety investment, and safety competency, ensures a holistic approach to enhancing safety culture. Furthermore, the application's design adheres to essential principles such as visibility, feedback, constraints, consistency, and affordances, resulting in an intuitive and user-friendly interface that promotes active engagement among all stakeholders. The real-time capabilities of the BOSCA allow for immediate feedback and proactive intervention, which are crucial in preventing incidents and maintaining a high standard of safety in the high-risk environment of the oil and gas industry. To address the identified limitations, future versions of BOSCA will explore enhanced API integration with legacy systems, improved modularity to adapt across industries, and expanded user onboarding features including gamified training and adaptive interfaces. These improvements aim to enhance system interoperability, reduce user resistance, and broaden BOSCA's applicability beyond the oil and gas sector.

4.7.4 Conclusion

The development of BOSCA marks a significant step forward in digital safety management for the oil and gas industry. By embedding critical behavioural elements into a cohesive digital framework, BOSCA provides a practical solution for strengthening proactive safety culture in high-risk settings. Built on user-centred design principles and cross-platform accessibility, the system supports continuous monitoring, timely feedback, and structured interventions. While these results support BOSCA's functional readiness, full-scale validation in operational environments will be reported in future studies. Despite its advantages, BOSCA's implementation may face challenges related to system integration and data privacy. Future development will focus on refining predictive analytics, broadening compatibility across industries, and enhancing user onboarding through adaptive features. Overall, BOSCA contributes to the ongoing evolution of safety culture management by offering a scalable, responsive, and behaviourally driven framework. It lays the groundwork for a more engaged, data-informed approach to managing safety in complex industrial operations.

4.8 Aim 7: Expert-Based Content and Design Validation of the Behavioural Occupational Safety Culture Application (BOSCA) [10]

Occupational safety management in high-risk industries such as oil and gas is governed by internationally recognised regulatory and management standards, including the Occupational Safety and Health Administration (OSHA) regulations (e.g., 29 CFR 1910) and ISO 45001:2018 (Kathayat et al., 2025). These frameworks emphasise hazard communication, worker competence, participation, incident reporting, and continual improvement as core pillars of effective safety management. However, organisations frequently face challenges in translating these regulatory requirements into sustained, day-to-day behavioural practice, particularly within geographically dispersed and operationally demanding environments typical of oil and gas operations. Occupational safety culture is widely recognised as a fundamental determinant of performance and risk management in high-hazard sectors (Sunday et al.,

[10] Rahim H., Dom C. N, Dapari R., (2024). Development and Expert-Based Content and Design Validation of the Behavioural Occupational Safety Culture Application (BOSCA). *Scientific Report*. (Submitted: Nov 2025)

2025 and Naji et al., 2021). In the oil and gas industry, the complexity of operations, presence of hazardous materials, and variability in human behaviour contribute to persistent incident rates and operational disruptions (Vital et al., 2023). Despite the existence of comprehensive safety management systems, occupational incident rates in Malaysia's oil and gas sector remain a concern, with reported accident and near-miss occurrences consistently exceeding those observed in several mature offshore jurisdictions (Alahjil et al., 2025). These patterns have been linked to behavioural non-compliance, inconsistent safety ownership across organisational levels, and difficulties in sustaining safety engagement in geographically dispersed and high-risk operational settings. Empirical evidence further underscores the central role of human and behavioural factors in workplace accidents, with previous studies estimating that 70–90% of occupational incidents involve unsafe acts, behavioural lapses, or failures in safety-related decision-making (Hale et al., 2012 and Stemn et al., 2019). As a result, strengthening behavioural safety culture encompassing management commitment, employee ownership, effective communication, and competency development has become a central focus of contemporary occupational safety strategies (Yazdi, 2025, Cooper, 2002 and Tang, 2025). This growing emphasis highlights the need for approaches that go beyond compliance-based systems to support continuous behavioural engagement and practical safety ownership in high-risk industrial environments.

Existing frameworks, including Hudson's Safety Maturity Model and Reason's Swiss-Cheese Model, have provided valuable conceptual insight into the relationship between human behaviour and organisational safety systems (Ayob et al., 2022). Despite the increasing adoption of digital platforms for occupational safety management, evidence suggests that many existing tools fail to achieve sustained behavioural engagement or meaningful safety culture transformation (Daniel et al., 2025). Common limitations include low user adoption due to complex interfaces, compliance-oriented designs that prioritise reporting over learning, and limited integration of behavioural reinforcement mechanisms. In addition, organisational factors such as hierarchical decision-making, fragmented safety communication, and competing operational demands often constrain consistent tool usage, particularly in high-risk industries. These barriers highlight that the effectiveness of digital safety tools is not solely determined by technological availability, but by their alignment with behavioural processes, user experience, and organisational context (Benson, 2019).

However, these models primarily serve diagnostic or assessment functions rather than continuous behavioural reinforcement (Fosdick et al., 2024 and Goncalves et al., 2010). Current digital tools adopted by the oil and gas sector often emphasise compliance tracking, audit reporting, or incident documentation, with limited capability to sustain behavioural engagement (Jahidi et al., 2024). Consequently, there remains a practical gap between theoretical understanding of safety culture and its translation into real-time, actionable practice. This gap is particularly evident in the oil and gas sector, where safety culture initiatives are frequently implemented as episodic training or compliance-driven programs, with limited mechanisms for continuous behavioural reinforcement, real-time feedback, or sustained worker engagement (Azmi et al., 2024 and Rahim et al., 2023). In this study, *behavioural engagement* refers to the sustained and active involvement of workers and managers in safety-related activities, including reporting, communication, learning, feedback, and self-monitoring of safe behaviours, rather than passive compliance with prescribed rules (Carra et al., 2024). *Real-time actionable practice* is defined as the ability of a safety system to provide immediate feedback, alerts, or performance insights that can directly inform and influence safety-related decisions and behaviours during ongoing operations (Kang, 2024). Accordingly, there remains a need for digital safety platforms that are explicitly designed to support behavioural engagement, instructional sequencing, and continuous interaction, while remaining usable and contextually appropriate for industrial environments (Hannah et al., 2025). This gap provides the rationale for the development and expert validation of the Behavioural Occupational Safety Culture Application (BOSCA).

Limited adoption of interactive technologies and the absence of validated behavioural tools hinder consistent monitoring and reinforcement of safe practices across hierarchical levels (Nnaji et al., 2020). The need for a locally contextualised, empirically validated digital platform that can bridge behavioural theory and field implementation has therefore become increasingly urgent. In this study, ‘locally contextualised’ refers to the deliberate alignment of the BOSCA platform with the Malaysian oil and gas operating environment. This includes integration with national occupational safety and health regulatory frameworks, prevailing organisational safety practices, dominant behavioural risk profiles, and culturally relevant approaches to communication, training, and leadership. Rather than adopting a generic safety application model, BOSCA was designed to reflect how safety is governed, communicated, and enacted within Malaysian industrial settings. Unlike conventional digital safety tools that rely on web portals or static reporting systems, BOSCA adopts a progressive web application (PWA) architecture specifically designed for oil and gas field conditions. This format enables cross-device accessibility, offline functionality in low-connectivity offshore or remote sites, and rapid task completion with minimal user burden (Tadi, 2022). These features directly address key barriers to digital tool adoption in oil and gas operations, including connectivity limitations, time-critical workflows, and the need for seamless integration into daily safety routines

To address this gap, the present study developed and validated the Behavioural Occupational Safety Culture Application (BOSCA), a progressive web application (PWA) designed to operationalise behavioural safety culture through interactive digital engagement. BOSCA integrates selected behavioural change theories, instructional design models, and technology acceptance principles to support proactive safety behaviours, continuous learning, and timely feedback within high-risk work environments. Specifically, this study aimed to: (i) develop a theoretically grounded digital framework for behavioural safety culture enhancement; (ii) design an interactive and user-friendly application interface informed by behavioural and instructional principles; and (iii) validate BOSCA's content, usability, and instructional integrity through expert consensus using the Fuzzy Delphi Technique (FDT). By achieving these objectives, the study contributes a validated methodological foundation for digital transformation in occupational safety management, demonstrating how behavioural safety theory can be translated into continuous, data-driven, and actionable practice. Through its PWA-based architecture tailored to the operational realities of the oil and gas sector, BOSCA directly addresses the gap between existing compliance-oriented digital tools and the need for sustained, behaviour-focused safety engagement in high-risk industrial settings.

4.8.1 Expert Characteristics

The socio-demographic characteristics of the expert panel are summarised in Table 4.15. This information is provided to describe the composition, professional background, and scope of expertise of the panel involved in the validation process, and to support the credibility and contextual relevance of the expert judgments. These characteristics form part of the methodological description of the sample and are not treated as analytical results. The 15 participants represented a balanced gender distribution (53.3% male, 46.7% female) with a mean age of 36.9 years (SD = 13.2). On average, experts had 15.2 years (SD = 12.8) of professional experience in occupational safety and health. Educational backgrounds ranged from diploma to postgraduate qualifications, ensuring input from both technical and managerial levels. In terms of position, 26.7% each were managers, executives, and non-executives, while senior executives and top management accounted for 13.3% and 6.7%, respectively. This multidisciplinary composition provided balanced insights from strategic, operational, and field-level perspectives, supporting the credibility of the BOSCA validation process by ensuring representation from diverse professional perspectives. Beyond demographic diversity, the expert panel was characterised by substantial practical experience in safety system implementation, behavioural safety initiatives, and organisational decision-making, supporting the credibility and contextual relevance of the validation outcomes.

Table 4.15
Socio-demographic Characteristics of Expert Panel

Characteristics	**n (%)**	**Mean (SD)**
Age		36.87 (13.21)
Sex		
• Male	8 (53.33)	
• Female	7 (46.67)	
Education Level		
• Degree	4 (26.67)	
• Diploma	3 (20.00)	
• SPM	3 (20.00)	
• Bachelor Degree	2 (13.33)	
• Master	2 (13.33)	
• Professional Certificate	1 (6.67)	
Working Experience (year)		15.20 (12.77)
Position Level		
• Operational level (*non-executive*)	4 (26.67)	
• Supervisory Level (*Executive*)	4 (26.67)	
• Managerial / Strategic Level (*Manager, Senior Executive, Top Management)*	7 (46.66)	

Note:
[1] The table presents the demographic and professional background of 15 experts involved in the BOSCA validation, showing balanced gender representation, varied education levels, and diverse job positions across different organisational tiers.
[2] SPM refers to *Sijil Pelajaran Malaysia*, the Malaysian Certificate of Education.
[3] Position levels were consolidated into three broad categories (Operational, Supervisory, and Managerial/Strategic) to improve clarity and comparability, while preserving the functional scope of expert roles represented in the validation panel.

4.8.2 Content Validation

This section presents the analytical outcomes of the expert validation process, focusing on consensus-based evaluation of BOSCA's content validity, interface design, interactivity, and instructional structure. Using the Fuzzy Delphi Technique, the results summarise expert agreement through threshold values, consensus percentages, and defuzzification scores across validation domains. These findings establish the robustness and usability of the BOSCA framework at the expert-validation stage and do not represent empirical evidence of behavioural change or improvements in occupational safety performance. For clarity and conciseness, acceptance decisions are summarised at the table level rather than repeated for individual items; unless otherwise stated, all items satisfied the predefined Fuzzy Delphi consensus criteria *($d \leq 0.2$; consensus $\geq 75\%$; $A \geq 0.5$)*

As presented in Table 4.16, all eight behavioural safety culture elements demonstrated strong expert agreement, fulfilling the acceptance criteria of $A > 0.5$, consensus $\geq 75\%$, and $d \leq 0.2$. Among these, *management commitment* ($A = 0.947$) and *safety ownership* ($A = 0.933$) recorded the highest defuzzification values, indicating their dominant influence on behavioural safety culture within the oil and gas context. Other key elements such as *safety communication* ($A = 0.927$), *reward and recognition* ($A = 0.933$), and *safety competency* ($A = 0.880$) also achieved full consensus, confirming their importance in shaping proactive safety behaviours. The Fuzzy Delphi Technique (FDT) was employed to evaluate expert consensus regarding the proposed BOSCA components. Respondents assessed each component using a seven-point linguistic scale ranging from strongly disagree to strongly agree. The responses were converted into triangular fuzzy numbers and analysed using the threshold value (d), percentage of expert agreement, and fuzzy score. Items satisfying the acceptance criteria of $d \leq 0.2$, expert agreement $\geq 75\%$, and α-cut ≥ 0.5 were considered accepted.

Table 4.16
Analysis of the Themes for the BOSCA

Item	Component	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
1	Management Commitment as a driving force for a proactive safety culture.	0.049	100.0	0.947

Item	Component	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
2	Employee Safety Commitment as a critical enabler for achieving safety objectives.	0.076	100.0	0.920
3	Fostering Safety Ownership across all organizational levels.	0.068	100.0	0.933
4	Continuous Safety Training to enhance employee skills and awareness.	0.073	100.0	0.907
5	Effective Safety Communication to disseminate critical safety information.	0.073	100.0	0.927
6	Reward and Recognition programs to incentivize safe behaviours.	0.068	100.0	0.933
7	Assessing Safety Competency to ensure employees are equipped for safe operations.	0.035	100.0	0.880
8	Strategic Safety Investment to support organizational safety initiatives.	0.073	100.0	0.907

Note: The table displays the eight key behavioural safety culture components and their corresponding validation metrics derived from the Fuzzy Delphi Technique (FDT). The *threshold value (d)* indicates the degree of consensus variation between experts (values ≤ 0.2 denote strong agreement), while the *expert group consensus (%)* reflects the proportion of experts in agreement. The *fuzzy score (A)* represents the overall acceptance level, with values ≥ 0.5 considered valid. All items met the acceptance criteria (d ≤ 0.2, consensus ≥ 75%, A ≥ 0.5), confirming that each component is appropriate for inclusion in the BOSCA framework.

The detailed subcomponent analysis in Table 4.17 further validated the functional adequacy of BOSCA's eight core modules: *rewards and recognition, incident reporting, safety audit, safety training, safety competency, communication alerts, safety enhancement,* and *management dashboard.* All sub-themes achieved acceptance thresholds, reflecting clear content structure, operational relevance, and alignment with industry practices. Collectively, these findings confirm that BOSCA's thematic framework accurately captures the essential behavioural dimensions of safety culture and provides a comprehensive digital structure for reinforcing positive safety behaviours across organisational levels. Although all evaluated components satisfied the predefined acceptance criteria, several components received comparatively lower scores than others. These findings should not be interpreted as deficiencies in the application but rather as opportunities for future enhancement. Components receiving lower scores may be further improved through interface redesign, enhanced interactivity, additional instructional content, incorporation of gamification features, or integration of user feedback obtained during future implementation and evaluation phases. Such improvements may contribute to greater user engagement and overall application effectiveness.

Table 4.17
Analysis of the Sub-themes for the BOSCA.

Item	Sub-Component	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
A. Rewards & Recognition				
1	Provides functionality for employees to independently nominate their peers for safety awards.	0.081	100.0	0.833
2	Nomination and selection processes are transparent and clearly communicated.	0.076	100.0	0.913
3	Reward categories are well-defined and aligned with the objectives of enhancing the safety culture.	0.076	93.33	0.913
4	Allows users to view the levels of employees recognized for specific achievements.	0.073	100.0	0.907
5	Recognition insights by department are provided.	0.081	100.0	0.833
6	Feature to view monthly awards or recognition summaries.	0.076	93.33	0.920
B. Incident Reporting				
1	Incident reporting process is straightforward and efficient.	0.081	80.0	0.833
2	Employees encouraged to report incidents and near-misses.	0.076	100.0	0.913
3	Incident reports are reviewed and acted upon promptly.	0.076	100.0	0.913
4	Reporting tools are accessible and easy to use.	0.073	100.0	0.907
5	Data used to prevent future occurrences.	0.081	80.0	0.833
6	Mechanisms ensure anonymity when required.	0.076	100.0	0.920
C. Safety Audit				
1	Audit process is systematic and well-structured.	0.058	86.67	0.844
2	Audit results presented clearly and comprehensively.	0.031	93.33	0.856
3	Employees actively participate in audits.	0.081	80.0	0.833
4	Audit findings lead to actionable improvements.	0.035	100.0	0.880
5	Audit tools are user-friendly and accessible.	0.073	100.0	0.907
6	Audits effectively track compliance.	0.035	100.0	0.880
D. Safety Training				
1	Training materials comprehensive and job-relevant.	0.000	100.0	0.867
2	Programs incorporate interactive content.	0.076	100.0	0.913
3	Access to regular refresher training.	0.073	100.0	0.907
4	Training outcomes measurable and tracked.	0.081	80.0	0.833

5	Modules updated to address new challenges.	0.068	100.0	0.900
6	Employees confident after training.	0.081	80.0	0.833
E. Safety Competency				
1	Assessments align with job-specific requirements.	0.058	86.67	0.844
2	Employees regularly evaluated for safety skills.	0.073	100.0	0.907
3	Skill gaps addressed with training programs.	0.076	100.0	0.920
4	Competency levels tracked and visualized.	0.076	100.0	0.920
5	Feedback supports continuous improvement.	0.031	93.33	0.856
6	Opportunities for professional development.	0.031	93.33	0.856
F. Communication Alert				
1	Real-time alerts for safety updates.	0.068	100.0	0.933
2	Communication channels are clear and effective.	0.060	100.0	0.893
3	Feedback on safety issues acknowledged promptly.	0.073	100.0	0.907
4	Employees notified of incidents timely.	0.081	80.0	0.833
5	Safety bulletins easy to access and understand.	0.068	100.0	0.933
6	Emergency communication reliable and accessible.	0.076	100.0	0.913
G. Safety Enhancement				
37	Application promotes continuous safety improvement.	0.081	80.0	0.833
38	Employees can submit suggestions.	0.068	100.0	0.933
39	Suggestions reviewed and implemented.	0.073	100.0	0.907
40	Enhancement initiatives tracked and evaluated.	0.076	100.0	0.913
41	Resources allocated for improvements.	0.073	100.0	0.907
42	Fosters innovation in safety practices.	0.060	100.0	0.893
H. Management Dashboard				
43	Dashboard provides real-time safety performance.	0.081	80.0	0.833
44	Key metrics clearly displayed and tracked.	0.060	100.0	0.893
45	Management can address safety issues easily.	0.076	100.0	0.920
46	Supports decision-making with insights.	0.068	100.0	0.900
47	Customizable views enhance usability.	0.060	100.0	0.893
48	Integrates data from safety activities.	0.076	100.0	0.920

Note: The *threshold value (d)* represents the degree of variance among expert judgments, where values ≤ 0.2 indicate strong consensus. The *expert group consensus (%)* shows the proportion of experts in agreement, and the *fuzzy score (A)* reflects the overall acceptance level of each sub-theme (A ≥ 0.5 denotes acceptance). All sub-components satisfied the Fuzzy Delphi acceptance criteria (d ≤ 0.2, consensus ≥ 75%, A ≥ 0.5), confirming the content validity and structural soundness of the BOSCA modules. All items presented in this table met the predefined Fuzzy Delphi acceptance criteria (threshold value d ≤ 0.2, expert consensus ≥ 75%, and defuzzification score A ≥ 0.5).

4.8.3 Presentation and Interface Design

As shown in Table 4.18, all items assessing BOSCA's presentation and interface design achieved strong expert consensus, meeting the acceptance criteria of A > 0.5, consensus ≥ 75%, and d ≤ 0.2. The experts unanimously agreed on the clarity, consistency, and aesthetic quality of the application's layout and colour composition. Elements such as screen simplicity, text readability, and navigation flow received particularly high agreement, with *language appropriateness* (A = 0.953) and *main menu usability* (A = 0.933) ranking among the highest-rated attributes. The integration of graphics, icons, and videos was also deemed effective for enhancing comprehension and engagement. Overall, the results indicate that BOSCA's interface design successfully balances visual appeal with functional usability, providing a clean, intuitive, and accessible platform suitable for diverse user groups within the oil and gas industry.

Table 4.18
Analysis of the Presentation Interface Design for the BOSCA.

Item	Sub-Component	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
1	Screen design is simple, attractive and consistent.	0.076	100.0	0.920
2	Text is straightforward and easy to read.	0.076	100.0	0.920
3	Integration of graphics, images, colours and icon buttons are attractive and appropriate.	0.049	100.0	0.887
4	Arrangement and structure of content is organised and engaging.	0.068	100.0	0.900
5	Image is realistic to apply the information.	0.076	100.0	0.913
6	Graphic elements used to convey information.	0.068	100.0	0.900
7	Video elements used to convey information.	0.076	100.0	0.913
8	Response time is appropriate.	0.073	100.0	0.927
9	Smooth transition between displays.	0.068	100.0	0.900
10	Language used is appropriate and easy to understand.	0.035	100.0	0.953
11	No technical glitches during application and presentation.	0.058	86.67	0.844
12	Navigation icons are user friendly.	0.076	100.0	0.913
13	Main menu system is simple and easy to use.	0.068	100.0	0.933

Note: The table presents expert evaluation results on BOSCA's visual and interface design. The *threshold value (d)* indicates variation among expert responses (values ≤ 0.2 show strong consensus), while the *fuzzy score (A)* reflects acceptance strength (A ≥ 0.5 denotes acceptance). All items achieved consensus, highlighting BOSCA's clear layout, readable text, smooth navigation, and user-friendly design. All items presented in this table met the predefined Fuzzy Delphi acceptance criteria (threshold value d ≤ 0.2, expert consensus ≥ 75%, and defuzzification score A ≥ 0.5).

4.8.4 Interactivity and Instructional Strategies

As shown in Table 4.19, the interactivity assessment revealed strong expert consensus across all evaluated items, meeting the acceptance criteria of $A > 0.5$, consensus $\geq 75\%$, and $d \leq 0.2$. Experts agreed that BOSCA effectively facilitates two-way communication, encourages user feedback, and supports easy navigation. Features such as structured information flow, multiple access options, and clear guidance for users were highlighted as key strengths that enhance overall usability and engagement.

Table 4.19
Analysis of the Interactivity Interface Design.

Item	Sub-Component	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
1	Encouraging feedback	0.081	80.0	0.833
2	Different forms of feedback	0.081	80.0	0.833
3	Provide links to other related websites	0.073	100.0	0.927
4	Scenarios and activities focus on intended achievement in the learning process	0.081	80.0	0.833
5	Systematic navigation structure	0.076	100.0	0.913
6	Easy-to-follow direction for presentation of information	0.076	100.0	0.920
7	Provides more than one form of information access	0.060	100.0	0.893
8	Eases access to needed information	0.076	100.0	0.920

Note: The table presents expert evaluation of BOSCA's interactive features. The *threshold value (d)* indicates the variation among expert responses (≤ 0.2 shows strong agreement), while the *fuzzy score (A)* reflects acceptance strength ($A \geq 0.5$ denotes acceptance). All items achieved consensus, confirming that BOSCA effectively supports user feedback, clear navigation, and easy access to information. All items presented in this table met the predefined Fuzzy Delphi acceptance criteria (threshold value $d \leq 0.2$, expert consensus $\geq 75\%$, and defuzzification score $A \geq 0.5$).

Similarly, the evaluation of instructional strategies (Table 4.20) achieved unanimous approval, confirming the theoretical and pedagogical robustness of BOSCA's learning framework. The integration of Gagné's Nine Events of Instruction and Bloom's Revised Taxonomy was recognised as effective in promoting knowledge acquisition, practice, and behavioural reinforcement. Experts particularly commended the clarity of learning objectives, logical sequencing of modules, and balanced use of multimedia elements (graphics and videos). Together, these findings affirm that BOSCA's interactive features and instructional design work cohesively to sustain user engagement, support behavioural change, and facilitate effective digital learning within safety culture training.

Table 4.20
Analysis of the Instructional Strategies.

Item	Sub-Components	The threshold value, d	Expert group consensus (%)	Fuzzy score (A)
1	Uses suitable theories and models to increase knowledge.	0.058	86.67	0.844
2	Uses suitable theories and models to promote behavioural changes.	0.058	86.67	0.844
3	Uses suitable theories and models for website development.	0.081	80.0	0.833
4	Uses suitable learning activities.	0.031	93.33	0.856
5	Clearly specifies the objectives of learning.	0.076	100.0	0.920
6	Has appropriate sequence of learning process.	0.073	100.0	0.927
7	Uses suitable media elements (graphics, video).	0.073	100.0	0.927
8	Supports learners in recalling prior knowledge.	0.076	100.0	0.913
9	Provides new learning stimuli.	0.068	100.0	0.900
10	Provides guidance.	0.058	86.67	0.844
11	Encourages practice.	0.076	100.0	0.920
12	Allows users and facilitators to provide feedback.	0.073	100.0	0.907
13	Duration is sufficient and not time-consuming.	0.076	100.0	0.920

Note: The table presents expert evaluations of BOSCA's instructional design elements. The *threshold value (d)* indicates variation among expert responses (≤ 0.2 shows strong consensus), and the *fuzzy score (A)* reflects the level of acceptance (A ≥ 0.5 denotes acceptance). All items achieved consensus, confirming that BOSCA applies appropriate theories, structured learning sequences, and effective multimedia elements to support user engagement and behavioural change.

4.8.5 Discussion

This study aimed to develop and validate the *Behavioural Occupational Safety Culture Application* (BOSCA), a theory-driven digital platform designed to operationalise behavioural safety culture frameworks within the oil and gas industry. The validation process successfully met this objective, confirming BOSCA's content accuracy, usability, interactivity, and instructional soundness. These findings indicate that digitally delivered behavioural safety frameworks can be developed as content-valid and usable interventions, with promising potential to support safety culture initiatives, pending empirical evaluation in operational settings. At this stage, the evidence supports the conceptual relevance and usability of the BOSCA platform rather than its effectiveness in producing behavioural change or measurable improvements in safety performance indicators. These findings demonstrate that a digitally delivered behavioural safety framework can be systematically designed and validated for conceptual accuracy, usability, and instructional integrity prior to empirical testing (Aderamo et al., 2024). While the present study did not include end-user testing or field-based evaluation, this is consistent with the staged development of digital safety interventions. Expert validation constitutes a critical prerequisite to ensure conceptual accuracy, contextual relevance, and functional reliability before implementation in high-risk operational settings. Introducing unvalidated digital safety tools directly into industrial environments may introduce usability, compliance, or safety risks. Therefore, the current findings provide a necessary foundation upon which subsequent user acceptance testing, pilot deployment, and longitudinal effectiveness evaluation can be systematically conducted.

Validation using the Fuzzy Delphi Technique (FDT) revealed unanimous expert consensus across all eight core behavioural safety culture themes; management commitment, employee commitment, safety ownership, safety training, safety communication, reward and recognition, competency assessment, and strategic safety investment. All components exceeded the acceptance thresholds ($A > 0.5$; consensus $\geq 75\%$; $d \leq 0.2$), indicating that experts strongly agreed on their relevance and clarity for inclusion in BOSCA. Among these, management commitment ($A = 0.947$) and safety ownership ($A = 0.933$) received the highest agreement, highlighting leadership's central role in fostering and sustaining a proactive safety culture. This outcome is consistent with previous studies by Stemn et al. (2019), and Zwetsloot et al. (2013), who identified management engagement and accountability as the cornerstone of a mature safety culture (Stemn et al., 2019 and Zwetsloot et al., 2013). The high consensus among experts supports the long-established notion that top-down commitment drives bottom-up behavioural compliance. The integration of these elements within BOSCA ensures that digital engagement aligns with established behavioural safety principles, bridging the traditional gap between management systems and employee practice (Zaman et al., 2025).

The sub-theme analysis further confirmed the robustness of BOSCA's eight functional modules; *rewards and recognition, incident reporting, safety audits, training, competency, communication alerts, safety enhancement,* and *management dashboard.* All modules achieved strong consensus, signifying that the platform's design and content appropriately reflect the operational realities of safety management in high-risk industries (Grote, 2012). Notably, modules related to *rewards and recognition* and *communication alerts* achieved the highest fuzzy scores, indicating their importance in sustaining motivation and ensuring continuous information flow. These findings align with prior work emphasised that effective communication and recognition systems are essential to reinforcing safe behaviours (Jitwasinkul et al., 2011 and Guo et al., 2018). The current results extend these findings by demonstrating that such mechanisms can be successfully embedded within a digital application, enabling real-time monitoring, feedback, and engagement across organisational levels.

The evaluation of BOSCA's presentation and interface design yielded complete expert consensus, confirming that the application's visual layout, colour scheme, and navigation system met user expectations for clarity and functionality. The *language appropriateness* (A = 0.953) and *main menu simplicity* (A = 0.933) achieved particularly high ratings, indicating that the design was intuitive and accessible to users of varying technical proficiency. These results are consistent with findings from earlier research by Sutcliffe (2022) and Johnson (2020), which demonstrated that clean, contrasting colour schemes and simplified user interfaces enhance digital comprehension and engagement (Sutcliffe, 2022 and Johnson, 2020). BOSCA's high usability reflects effective integration of human–computer interaction principles, validating its capability to engage users in an industrial safety setting where simplicity and speed are critical.

Assessment of interactivity confirmed that BOSCA facilitates meaningful two-way communication, enabling feedback, information sharing, and multiple access options for users. The inclusion of clear navigational pathways and responsive design ensures efficient interaction between workers and safety administrators. Similarly, instructional strategies achieved unanimous expert approval, validating BOSCA's theoretical foundation derived from *Gagné's Nine Events of Instruction* and *Bloom's Revised Taxonomy.* These frameworks structured the learning modules from knowledge acquisition to behavioural reinforcement, ensuring progressive engagement and cognitive development. These findings align with previous educational technology research , reported that interactive and sequentially structured instructional designs significantly improve retention and performance (Hultberg et al., 2018). BOSCA's integration of multimedia elements; graphics, infographics, and video supports multimodal learning, consistent with Maqbool et al. (2025), who demonstrated that behaviour change interventions are more effective when supported by visual and interactive cues (Maqbool et al., 2025).

The consistency between BOSCA's validation results and existing safety culture research underscores its theoretical soundness. However, BOSCA extends prior frameworks by translating behavioural models such as the *Unified Theory of Acceptance and Use of Technology (UTAUT)*, *Flow Theory*, and the *Transtheoretical Model of Change (TTM)* into a functional digital system. Unlike earlier behavioural safety initiatives that relied on manual observation or paper-based training (Ong et al., 2016), BOSCA operationalises these theories into real-time, data-driven engagement mechanisms. Where differences from earlier work exist, they can be attributed to BOSCA's integration of technology acceptance principles that address digital readiness and user motivation factors not considered in traditional behavioural safety models. This advancement highlights the evolving role of digital transformation in occupational safety and health, especially within complex industries such as oil and gas (Haoule et al., 2024). By embedding regulatory expectations, organisational practices, and culturally grounded behavioural norms into its design, BOSCA extends beyond a generic digital safety tool and offers a context-sensitive framework that is more likely to be adopted and sustained within Malaysian industrial environments.

Although multiple theoretical frameworks informed BOSCA's design, their application was intentionally selective and function specific. Technology acceptance (UTAUT) guided usability and access, engagement theories (Flow) informed interaction design, behavioural readiness (TTM) shaped learning progression, and instructional theories (Gagné and Bloom) structured content delivery. The convergence of expert consensus across validation domains provides empirical support that these theoretical elements were successfully operationalised, rather than merely cited, within the BOSCA platform. It is important to distinguish between validation outcomes and effectiveness outcomes. The present study establishes BOSCA's content validity, usability, interactivity, and instructional soundness through expert consensus, which are necessary prerequisites for behavioural safety interventions. However, these findings do not constitute evidence of actual behavioural change or improvements in occupational safety and health (OSH) performance indicators. Any references to behavioural influence or operational impact in this manuscript should therefore be interpreted as conceptual and prospective, pending empirical verification through field-based implementation and outcome evaluation.

The present validation focused on expert consensus regarding BOSCA's content, interface design, interactivity, and instructional structure. Although these dimensions are essential prerequisites for behavioural safety interventions, they do not constitute empirical evidence of behavioural change or improvements in safety performance. Accordingly, any references to behavioural influence or operational impact in this study should be interpreted as conceptual and prospective, pending verification through field-based implementation and outcome evaluation. Within this validated scope, the findings demonstrate that BOSCA is theoretically grounded and practically relevant as a digital framework, with its progressive web application (PWA) architecture offering enhanced accessibility through cross-device compatibility and offline functionality features particularly suited to remote and offshore operations. Nevertheless, as this study represents an expert-validation phase only, user acceptance, behavioural adoption, and operational effectiveness could not be assessed. Future research will therefore involve pilot implementation with workers and managers, integrating usability and user experience testing alongside longitudinal assessment of safety outcomes such as near-miss reporting frequency, behavioural compliance, and incident trends. In parallel, minor expert recommendations, including enhanced interactivity features and the integration of external safety resources, will inform subsequent iterations of BOSCA to further strengthen user engagement and practical impact.

4.8.6 Conclusion

In summary, the validation findings strongly support the study's objective of developing a theory-driven, user-centred digital intervention to strengthen behavioural safety culture in the oil and gas industry. The consistency of BOSCA's results with prior behavioural safety research underscores its credibility, while its digital implementation introduces an innovative, scalable approach to safety culture management. Through its validated content, interactive design, and instructional integration, BOSCA bridges the gap between behavioural theory and practical application offering a validated digital foundation for behavioural safety initiatives, upon which future empirical studies can evaluate behavioural adoption and impacts on OSH performance indicators.

CHAPTER 5
SUMMARY AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions of the study based on the research objectives, highlights the theoretical and practical contributions, discusses the limitations of the study, and proposes recommendations for future research. The chapter concludes by summarising the significance of the Behavioural Occupational Safety Culture Application (BOSCA) in supporting proactive safety culture practices within the Malaysian oil and gas industry.

5.2 Summary of the Results

The first objective was successfully achieved through a systematic literature review, Analytic Hierarchy Process (AHP), and Structural Equation Modelling (SEM). The findings identified three principal safety culture dimensions, namely psychological, behavioural, and situational. AHP analysis revealed that the behavioural dimension was the most preferred category among stakeholders, followed by situational and psychological dimensions. Within the behavioural dimension, management commitment, safety ownership, and safety communication emerged as the most influential elements. SEM analysis further confirmed that the behavioural construct demonstrated the strongest contribution to safety culture compared with the other dimensions. These findings provide empirical support for prioritising behavioural factors in safety culture interventions within the Malaysian oil and gas industry.

The second objective was achieved through the development of BOSCA, a Progressive Web Application (PWA) designed to operationalise the prioritised behavioural safety culture elements. The application incorporates modules related to management commitment, safety commitment, safety ownership, safety training, safety communication, reward recognition, safety investment, and safety competency. The development process was guided by established instructional, behavioural, and technology adoption theories to ensure that the application supports proactive safety culture practices and user engagement.

The third objective was successfully achieved through expert validation and user acceptance evaluation. The Fuzzy Delphi Technique (FDT) results indicated that all evaluation items satisfied the predefined acceptance criteria (threshold value $d \leq 0.2$, expert agreement $\geq 75\%$, and α-cut ≥ 0.5). The user acceptance assessment further demonstrated positive perceptions regarding usability, usefulness, and intention to use the application. These findings indicate that BOSCA is a valid, acceptable, and suitable digital intervention for supporting proactive safety culture practices in the Malaysian oil and gas industry.

5.3 Contribution of the Study

This study contributes to theory by providing an empirically validated safety culture framework consisting of psychological, behavioural, and situational dimensions. The integration of systematic review, AHP, and SEM offers a structured approach for identifying, prioritising, and validating safety culture dimensions. From a methodological perspective, the study demonstrates the application of multiple complementary techniques, including systematic review, CVR, EFA, AHP, SEM, and FDT, in the development and evaluation of a safety culture intervention framework. From a practical perspective, the study contributes the BOSCA application as an evidence-based digital intervention designed to strengthen proactive safety culture practices. The findings may assist organisations, regulators, and policymakers in developing more targeted safety culture initiatives, particularly within high-risk industries.

5.4 Implications of the Study

The findings have implications for industry practitioners, regulators, and policymakers. Industry organisations may utilise the identified behavioural safety culture elements to strengthen safety management strategies and employee engagement initiatives. Regulatory agencies may use the validated framework as a reference for safety culture assessment and improvement programmes. The study also supports the objectives of Malaysia's Occupational Safety and Health Master Plan (OSHMP25) in promoting a preventive and proactive safety culture across workplaces.

5.5 Limitations of the Study

This study possesses several notable strengths. It adopts a comprehensive methodological approach by combining systematic review techniques, psychometric validation, AHP-based prioritisation, and IPA performance analysis. This multi-layered design allows for a deep and holistic understanding of safety culture, bridging evidence synthesis with empirical evaluation and industry-driven prioritisation. Another strength lies in the development of the SCQ, which is specifically tailored to the oil and gas industry and addresses measurement gaps in existing safety culture instruments. Additionally, the involvement of diverse stakeholder groups enhances the relevance and applicability of the findings, ensuring that the perspectives of practitioners, managers, regulators, and scholars are adequately represented.

Despite these strengths, the study is not without limitations that should be considered when interpreting the findings. First, the validation of the Behavioural Occupational Safety Culture Application (BOSCA) was confined to expert consensus using the Fuzzy Delphi Technique and did not involve empirical testing with intended end users such as frontline workers or HSE personnel. Consequently, user acceptance, practical usability, behavioural adoption, and real-world operational effectiveness could not be assessed at this stage. In addition, the validation focused primarily on design-level attributes including content relevance, interface design, interactivity, and instructional integrity, rather than outcome-level indicators. As a result, behavioural change and occupational safety and health (OSH) performance outcomes were not evaluated.

Second, while the study examined psychological, behavioural, and situational safety culture elements, these constructs were analysed largely in isolation. As highlighted in Chapter 4, the interdependencies among these dimensions were not explicitly modelled, despite their potential to exert a combined and dynamic influence on safety outcomes. Third, although the size and multidisciplinary composition of the expert panel were appropriate for Delphi based validation, the findings may have limited generalisability across different organisational, industrial, or regulatory contexts. This limitation is further compounded by the study's focus on the Malaysian context, where safety culture practices may differ from those in other countries or industries.

Finally, the predominantly cross-sectional nature of the study restricts insights into how safety culture and behavioural engagement may evolve over time or in response to sustained digital interventions. While technology-related predictors emerged as an important area of interest, the study did not fully examine issues related to digital safety governance, automation-driven behavioural adaptation, or long-term system integration. These limitations are inherent to the design and development phase of digital intervention research. Consistent with the Design and Development Research approach adopted in this study, end-user involvement, field deployment, and empirical effectiveness evaluation represent subsequent validation stages and will be addressed through future pilot implementations and longitudinal studies within operational settings.

5.6 Recommendations

Based on the findings of this study, several recommendations can be made to strengthen safety culture practices within the oil and gas industry. First, it is essential for organisations to prioritise interventions that reinforce behavioural determinants of safety, as these were consistently identified as the most influential predictors of positive safety outcomes. Management commitment should be visibly demonstrated through active participation in safety initiatives, transparent decision-making, consistent communication during routine operations and emergencies, and modelling of desired safety behaviours. Strengthening safety ownership among employees is equally important, particularly by promoting accountability, empowering workers to identify hazards, and rewarding proactive safety behaviour. Effective communication both top-down and bottom-up should be emphasised to ensure that safety expectations, procedures, and feedback mechanisms are clearly understood across all organisational levels. Behavioural reinforcement strategies, such as recognition programmes, coaching, and peer-to-peer safety advocacy, should be embedded into daily operations to sustain positive behaviours.

A second recommendation concerns the enhancement of situational and environmental conditions. Organisations should invest in improving safety rules enforcement through stricter monitoring, clearer procedures, and more transparent disciplinary mechanisms. Attention should also be given to strengthening reporting systems to encourage open, blame-free reporting of near misses, unsafe conditions, and incidents. Ensuring equipment reliability through preventive maintenance and timely replacement will reduce operational risks and support safer working environments. Improvements to the physical work environment, including ergonomic design, lighting, ventilation, and housekeeping, are also crucial for creating settings that support safe behaviour and reduce exposure to hazards. Training and competency development form the third major recommendation. Training programmes should be aligned closely with the prioritised safety culture elements identified from the AHP analysis. This includes developing modules that enhance risk perception, strengthen safety knowledge, and improve job satisfaction factors shown in this study to influence attitudes and behaviours toward safety. Training should adopt interactive, scenario-based methods tailored to the realities of the oil and gas industry, incorporating the use of digital tools such as the BOSCA App to reinforce learning and encourage continuous engagement. Competency assessments should be conducted regularly to monitor progress and identify areas requiring additional support.

The fourth recommendation relates to organisational planning and resource allocation. The IPA matrix developed in this study provides a strategic decision-making tool that organisations should adopt to prioritise safety culture investments. Elements classified as high importance, but low performance must receive immediate attention, including targeted funding, leadership involvement, and structured improvement plans. Conversely, elements that fall into the over-performance quadrant where performance exceeds strategic value should prompt organisations to reconsider whether existing resources could be redistributed to areas of greater need. This structured approach allows organisations to optimise safety investments, avoid misallocation, and ensure that improvement efforts are both impactful and cost-effective. In addition, organisations should adopt the validated Safety Culture Questionnaire (SCQ) as part of their routine monitoring and evaluation processes. Its strong psychometric properties, industry relevance, and comprehensive structure make it a valuable tool for diagnosing safety culture strengths and weaknesses. Regular administration of the SCQ whether quarterly, biannually, or annually will enable organisations to track changes over time, evaluate the effectiveness of interventions, and inform continuous improvement cycles. The SCQ should be integrated into broader safety management systems, complementing incident data, audits, and behavioural observations.

Lastly, this study highlights the need for regulators and policymakers to revisit national safety frameworks and incorporate the prioritised safety culture elements that emerged from the findings. Emphasis should be placed on behavioural reinforcement strategies, leadership accountability, communication systems, and readiness for digital transformation. Regulators should encourage or mandate the use of validated instruments such as the SCQ, support the adoption of digital safety tools like BOSCA, and promote policies that enhance technology integration in safety governance. Doing so will not only ensure consistency across organisations but also strengthen Malaysia's overall regulatory environment for managing safety in high-risk industries. Overall, these recommendations provide a structured and actionable pathway for organisations, practitioners, and policymakers to enhance safety culture in the oil and gas industry by implementing evidence-based strategies grounded in the findings of this research.

5.7 Directions for Future Research

The findings of this study open several important avenues for future research, particularly in advancing the theoretical, methodological, and technological dimensions of safety culture research. One major direction involves examining the interdependencies among psychological, behavioural, and situational factors in a more integrated and dynamic manner. While the present study analysed these domains individually, future research should explore how they interact and reinforce one another within complex organisational systems. Advanced analytical approaches—such as network analysis, systems thinking, causal loop modelling, and longitudinal structural equation modelling would allow researchers to capture these dynamic relationships and identify critical leverage points where targeted interventions could generate amplified improvements in safety culture. Such approaches can deepen understanding of the causal pathways and feedback loops that shape safety behaviour in high-risk industries.

A second promising area for future work involves expanding the application of the validated Safety Culture Questionnaire (SCQ) to other high-risk sectors beyond the oil and gas industry. Sectors such as construction, manufacturing, maritime operations, aviation, and renewable energy share many similar hazards and operational challenges, making them ideal environments for testing the generalisability and adaptability of the SCQ. Comparative studies across sectors and countries would provide valuable insights into contextual variations in safety culture, highlight universal versus industry-specific predictors, and contribute to the development of globally relevant frameworks for safety culture assessment. Such cross-sector validation would also enhance the robustness and applicability of the SCQ as a standardised measurement tool.

Future research would also benefit from employing longitudinal research designs to track the evolution of safety culture over time. Safety culture is inherently dynamic, influenced by organisational changes, technological advancements, leadership transitions, training initiatives, regulatory updates, and internal incident histories. Longitudinal studies would allow researchers to observe how safety culture indicators shift in response to these changes, assess the sustainability of interventions, and generate evidence on the long-term effectiveness of safety improvement strategies. These insights are critical for understanding not only what enhances safety culture, but also what maintains it over extended periods. Given the increasing digitalisation of industrial operations, future research should explore digital safety governance as an emerging and essential safety culture dimension. Areas such as automation trust, human–machine interaction, digital literacy, predictive analytics, sensor-based monitoring, and AI-assisted decision support should be examined for their influence on safety behaviours and organisational risk perception. Studies could investigate how digital tools—such as the BOSCA App developed in this research shape worker engagement, hazard awareness, compliance behaviour, and safety communication. Understanding how digital platforms can be optimised to support safety culture transformation will become increasingly relevant as industries transition toward Industry 4.0 and cyber-physical systems.

Another area requiring further attention is the need for broader stakeholder representation in safety culture research. The present study included stakeholders from multiple backgrounds, yet future studies should incorporate perspectives from more diverse operational groups, including offshore workers, contractors, front-line technicians, maintenance personnel, emergency responders, and part-time or transient workers. This is especially important because these groups often work in environments with heightened exposure to hazards, varied supervisory structures, and differing safety expectations. Their inclusion would enrich the understanding of safety culture and lead to more inclusive, equitable, and context-sensitive safety interventions.

Finally, future research should integrate qualitative approaches such as ethnography, focus groups, and in-depth interviews—to complement quantitative findings and provide richer contextual insights. Such mixed-methods designs can capture tacit behaviours, cultural nuances, and organisational narratives that are not easily measurable using structured instruments. This would create a more holistic understanding of how safety culture is lived and perceived across different organisational layers. In summary, future research should extend the analytical depth of safety culture studies, broaden their contextual reach, incorporate digital transformation trends, and embrace methodological diversity to produce more comprehensive, actionable, and future-ready insights for safety management in high-risk industries.

5.8 Conclusion

In conclusion, establishing a universally applicable safety culture framework remains challenging because safety culture characteristics, organisational practices, operational risks, and regulatory requirements vary significantly across industries. Consequently, the safety culture elements and interventions that are effective in one industry may not be directly transferable to another. Within the Malaysian context, further research is required to examine the interrelationships among psychological, behavioural, and situational safety culture dimensions across various industries. Such efforts would support the objectives of the Occupational Safety and Health Master Plan 2025 (OSHMP25) in promoting a proactive and preventive safety culture across all workplaces. The high-risk nature of the oil and gas industry requires safety management approaches that extend beyond regulatory compliance. As demonstrated in this study, proactive safety culture plays a critical role in strengthening safety awareness, reducing unsafe behaviours, encouraging employee participation, and preventing workplace incidents before they occur. The development of BOSCA represents a significant contribution by translating validated safety culture dimensions into a practical digital intervention capable of supporting continuous safety engagement and improvement. Ultimately, fostering a proactive safety culture is essential for achieving sustainable safety performance, preventing major accidents, and creating safer work environments within the oil and gas industry and beyond.

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APPENDICES

APPENDIX A
Ethics Approval

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UNIVERSITI TEKNOLOGI MARA | Pejabat Timbalan Naib Canselor (Penyelidikan dan Inovasi)

Reference : 600-TNCPI (5/1/6)
Our reference : REC/07/2023 (PG/MR/251)
Date : 21 July 2023

Assoc. Prof. Dr Nazri bin Che Dom
(Mohd Hafiz bin Rahim – 2022413376)
Centre of Environmental Health and Safety
Faculty of Health Sciences
UiTM Puncak Alam Campus
42300 Puncak Alam
SELANGOR

Dear Assoc. Prof. Dr Nazri,

APPROVAL LETTER - UiTM RESEARCH ETHICS COMMITTEE

Thank you for submitting your research proposal to the Research Ethics Committee (REC). After considering your application, the Committee approved your proposal titled "Design and Development of Mobile Application Based on Proactive Elements of Safety Culture Framework for Oil and Gas Industry" at the Faculty of Health Sciences, UiTM Puncak Alam Campus.

Details of the approval are as follows:

Ref. number:	REC/07/2023 (PG/MR/251)
Approval Period:	21 July 2023 until 1 September 2024
Authorised personnel:	1. Assoc. Prof. Dr Nazri bin Che Dom 2. Mohd Hafiz bin Rahim

The UiTM Research Ethics Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The approval of this project is conditional upon your continuing compliance with these guidelines and declaration.

We draw to your attention the requirement that a report on this research, must be submitted every 12 months from the date of the approval or on the completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed. Amendments, if any, to the study documents are to be submitted to the REC for approval.

If you require further information, please contact the REC Secretariat at 03-55448069/03-55442794 or email at recsecretariat@uitm.edu.my.

Yours sincerely,

EMERITUS PROFESSOR DATO' DR RAYMOND AZMAN ALI
Chairman
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APPENDIXES B

Publication 1

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scientific reports

OPEN

Decoding stakeholder priorities of safety culture preferences in the oil and gas industry

Hafiz Rahim[1,5], Rahmat Dapari[2]✉, Nazri Che Dom[1,4] & Mohd Iqbal Mohd Noor[3]

Safety culture is a critical determinant of organisational performance, particularly in high-risk industries especially in oil and gas. Understanding stakeholder preferences is essential for developing effective strategies that enhance safety culture. This study utilised the Analytic Hierarchy Process (AHP) to prioritise stakeholder preferences, identifying key elements of safety culture in Malaysia's oil and gas sector. This study employed a structured methodology to evaluate safety culture within the oil and gas industry, focusing on 18 sub-elements across three key domains: psychological, behavioural, and situational factors. A diverse sample of industry experts was recruited using purposeful and snowball sampling to ensure a comprehensive representation of stakeholder views. The AHP framework was applied to analyse the data, utilizing structured questionnaires and multicriteria decision-making techniques to prioritize the identified safety culture elements. The AHP analysis identified distinct priorities among different professional groups within the oil and gas sector. Safety and Health Practitioners emphasized practical elements such as safety rules and management commitment, while academicians prioritized knowledge and training. Management personnel highlighted the importance of safety ownership and communication, whereas policymakers focused on broader, policy-oriented aspects. The findings suggest that safety culture improvement initiatives should be tailored to address the specific needs and priorities of each professional group. A nuanced understanding of stakeholder preferences is crucial for developing comprehensive strategies that integrate observable behaviours, situational conditions, and psychological factors, ultimately fostering a robust safety culture in the oil and gas industry.

Keywords Safety culture, Elements, Analytical hierarchy process (AHP), Oil and gas, Stakeholder, Prioritization

Safety culture in the oil and gas industry is paramount to ensure operational safety as well as to safeguard human lives and the environment[1–3]. Safety culture refers to the shared attitudes, beliefs, perceptions, and values that employees hold regarding safety within an organisation[4–6]. It encompasses the commitment to safety at all levels of the organisation, influencing behaviour and decision-making processes aimed at preventing accidents and promoting a safe working environment[7]. Comprehensive integration of safety culture into the workplace environment is crucial as it forms one of the cornerstones of the holistic Health, Safety, and Environment (HSE) culture[8]. Without a comprehensive safety culture, the repercussions can be profound, directly causing accidents and injuries among oil and gas workers. Hence, robust accident prevention measures are vital in this sector[9–11].

In Malaysia, the oil and gas sector is a major contributor to the nation's economy[12]. As one of the largest contributors to the nation's GDP, the oil and gas sector significantly impacts Malaysia's economic stability and growth[13]. However, it is also associated with inherent risks stemming from suboptimal safety management practices[14–16]. Diverse regulatory practices, cultural influences on safety perceptions, and varied organisational safety practices further complicate the establishment of a unified safety culture across the industry[17,18]. Moreover, the safety landscape is highly dynamic as shaped by continuous technological advancements and evolving regulatory frameworks. Hence, an adaptable and responsive approach to safety culture development plays an important role in this industry[19,20]. In Malaysia, the oil and gas industry has been the subject of numerous

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Publication 2

Malaysian Journal of Medicine and Health Sciences (eISSN 2636-9346)

ORIGINAL ARTICLE

Safety Culture Maturity Assessment: Insights and Improvement Opportunities for the Oil and Gas Sector

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ABSTRACT

Introduction: Assessing safety culture maturity is crucial for organizations to evaluate safety performance and identify areas for improvement. Without such assessments, companies may focus on nonspecific problems, hindering progress despite safety initiatives. This study assesses safety culture maturity within the Malaysian oil and gas industry and identifies specific areas for improvement. **Materials and methods:** A survey was conducted using a questionnaire based on the five HSE safety ladder dimensions, evaluating 18 key dimensions of safety culture including communication, leadership commitment, rewards and recognition, incident perception, HSE and profitability, contractor management, training and competency, HSE department efficacy, intervention practices, consequence management, process safety, procedural adherence, incident investigation, hazard reporting, lessons learned, safety meetings, auditing processes, and HSE benchmarking. **Results:** Organizations have made significant strides in achieving a generative level of safety culture maturity. However, dimensions such as incident perception, training and competency, and leadership engagement require improvement. Addressing these gaps through robust incident reporting and response mechanisms, continuous training programs, proactive leadership involvement, and enhanced communication can significantly enhance safety culture. **Conclusion:** This study provides insights into factors influencing safety culture maturity and offers a framework for targeted interventions to enhance safety practices. The findings underscore the importance of continuous assessment and targeted improvements in maintaining high safety performance. These insights are crucial for professionals in high-risk sectors aiming to develop a dynamic and inclusive safety culture.
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Keywords: Safety culture, Culture maturity level, Oil and gas, Organizational safety, Improvement

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INTRODUCTION

Integrating safety culture into a company's operations is essential to ensuring a safe and sustainable work environment. However, implementing safety culture is not always easy, as it requires a holistic approach that covers a wide range of knowledge areas. One of the biggest challenges in implementing safety culture is identifying personal attitudes toward the perceptions, beliefs and values that form the basis of safety culture. Safety culture refers to the shared values, attitudes, and beliefs about safety that drive behavior in an organization (1). Other studies emphasize specific outcomes of a strong safety culture, including the assessment of an organization's overall health and safety performance. This includes evaluating how well the organization manages health and safety risks and the effectiveness of measures implemented to reduce hazards (2, 3). It is a critical element of safety culture because it influences how employees perceive and respond to risks. However, it can be difficult to identify and measure personal attitudes toward safety culture because they are often influenced by individual factors such as upbringing, education, and personal experiences. Safety culture also requires a comprehensive, integrated vision of a systemic approach. This includes the interactions and connections among the various elements-context, organization, people, and technology-rather than looking at individual elements in isolation (4). An effective safety culture requires an understanding of all these systemic approaches and their interrelationships to ensure that the organization's safety goals are aligned with overall business objectives (5). In addition, the maturity of the safety culture may be limited by the organization's ability to integrate these knowledge domains. For example, an organization may have sound risk management practices, but if its operational practices are not aligned with its safety goals, it may not be able to achieve a high level of safety culture maturity.

Publication 3

Malaysian Journal of Medicine and Health Sciences (eISSN 2636-9346)

ORIGINAL ARTICLE

Development and Validation of a Questionnaire on Safety Culture Elements Preference for Oil and Gas Industry

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ABSTRACT

Introduction: The oil and gas industry is characterized by its inherently high-risk environment, necessitating a robust safety culture to prevent accidents and protect employees. Given the sector's complexity and the critical nature of its operations, a systematic assessment of safety culture is essential for enhancing safety performance. However, there remains a notable absence of standardized tools specifically designed to measure safety culture within the oil and gas industry. This study aims to develop and validate a Safety Culture Questionnaire (SCQ) tailored for the oil and gas industry to systematically assess safety culture. **Materials and methods:** The SCQ was developed based on an extensive literature review and consultation with academician and industry experts. The questionnaire is structured based on four key constructs derived from safety culture frameworks: psychological (6 items), situational (15 items), behavioural (28 items), and element preference (3 items), totaling 52 questions. Content validity was assessed by a panel of seven experts, and reliability was evaluated using Cronbach's Alpha. **Results:** The Content Validity Index (CVI) ranged from 0.86 to 1.00, indicating strong validity. Cronbach's Alpha values demonstrated excellent reliability: 0.926 (psychological), 0.923 (situational), 0.982 (behavioural), and 0.912 (element preference). **Conclusion:** The validated SCQ is a reliable and valid tool for assessing safety culture in the oil and gas industry. It can be used to identify safety culture strengths and weaknesses, enabling organizations to target interventions more effectively and ultimately improve safety culture.
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Keywords: Safety culture, Oil and gas, Questionnaire development, Validity, Reliability

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INTRODUCTION

In the high-risk oil and gas industry, where accidents can lead to severe consequences, establishing a robust safety culture is crucial. Safety culture in this context refers to the way in which safety is managed in the workplace, encompassing attitudes, beliefs, perceptions and values shared by employees at all levels (1-2). Despite the critical importance of safety culture, measuring it accurately and effectively has remained a challenge, particularly due to the diverse operational contexts and geographic regions in which these industries operate (3). Historically, attempts to quantify safety culture have utilized various methodologies, but often without sufficient validation to ensure their effectiveness across different industries and operational settings (4). This has led to the development of tools that may not fully capture the nuances of safety culture in specific contexts, particularly in an industry as complex and varied as oil and gas. In response to this, there has been a growing emphasis on the need for a scientifically rigorous approach to developing these assessment tools (5,6).

A variety of tools have been developed to assess safety culture, including the Safety Attitudes Questionnaire (SAQ) and the IATA Aviation Safety Culture Survey (IASC), which have been used in sectors such as healthcare and aviation. (7, 8). The SAQ focuses on measuring attitudes and perceptions related to teamwork, safety climate, and job satisfaction, while the IASC surveys emphasize compliance and organizational

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A MAPPING REVIEW ON SAFETY CULTURE IN MALAYSIAN INDUSTRIES: A RESEARCH REPORT FROM 2007 TO 2022

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Abstract: Optimising a company's safety culture is a tool for reducing and preventing workplace accidents. However, the variables that affect safety culture across industries have not been thoroughly studied and are rarely discussed in previous research. The objective of this study is to identify the factors that affect a company's safety culture across industries in Malaysia over the past decade. In this systematic review study, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method was used. The Scopus and Web of Science databases were used for these qualitative studies, which identified seven industries engaged in safety culture research between 2007 and 2022. The research found that behavioural factors were the most important aspect of safety culture, followed by situational and psychological factors. Nineteen elements of safety culture and three main research objectives of safety culture in different industries were identified within the study period. In addition, a different preference for the elements of safety culture was found in different industries in Malaysia. In conclusion, a systematic review study provides researchers, companies, practitioners, and policy makers with a snapshot of the Malaysian safety culture landscape and the elements preferred by different industries to reduce occupational accidents in the future.

Keywords: Safety culture, gaps analysis, Malaysia, systematic review, safety culture elements.

Introduction

Safety culture is considered a key element that confirms the context for an organisation's awareness of the importance of safety (Schulman, 2020). Furthermore, safety culture reflects and constructs organisational psychological and behavioural characteristics that can influence the success or failure of occupational safety and health programmes (OHS) (Tear *et al*., 2020). With the growing awareness of safety culture as a key indicator of organisational safety outcomes, regulators in various industries have begun to emphasise safety elements in their business requirements and audits (Naevestad *et al*., 2019). With this in mind, it is not surprising that significant efforts are being made to develop an evidence-based OHS strategy to address a variety of safety issues across numerous industries (Cunningham *et al*., 2020).

The rapid growth of industrialisation has had a significant impact on income inequality and quality of life, but it has also contributed to an increase in occupational accidents. Each organisation has different elements of adaptive safety culture that help to improve safety performance (Beus *et al*., 2010). Accident reports in Malaysia are compiled and managed by the Department of Occupational Safety and Health (DOSH) Malaysia, allowing for continuous assessment of safety performance in all industrial sectors. The number of injury cases is increasing in all industries. Malaysia's national occupational injury statistics recorded 21,534 cases for all industries in 2021, with an injury rate of 1.43 per 1,000 workers (DOSM, 2022). However, the literature on safety culture rarely discusses beyond the variables of safety

APPENDIXES C

Conferences

Conference

1. 1st International Conference on Sustainable Environment, Development and Energy (CONSER). 2022. Bali, Indonesia. IOP Conference Series: Earth and Environmental Science
   Title: Design and Development of Mobile Application Based on Proactive Elements of Safety Culture Framework for the Oil and Gas Industry: A Conceptual Framework.
2. 10th International Conference on Science & Social Research (CSSR), 6th – 7th November 2023. Safety Culture Maturity Assessment: Insight and Improvement Opportunities for the Oil and Gas Sector.


Certificate of APPRECIATION

CSSR 2023

10th INTERNATIONAL CONFERENCE ON SCIENCE & SOCIAL RESEARCH

This is to certify that

MOHD HAFIZ RAHIM

has presented orally a paper entitled

Assessing Safety Culture Maturity in Downstream Oil and Gas Organization: Current

during

10th INTERNATIONAL CONFERENCE ON SCIENCE & SOCIAL RESEARCH (CSSR) 2023

6th - 7th November 2023

PROF. TS. DR NORAZAH ABD RAHMAN
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AUTHOR’S PROFILE

Mohd Hafiz Rahim completed his Doctor of Philosophy (PhD) in Environmental Health and Safety at the Faculty of Health Sciences, Universiti Teknologi MARA (UiTM), Malaysia. He commenced his doctoral journey in September 2022 while concurrently pursuing a full-time career in the private sector oil and gas industry. He has over 15 years of professional experience in the oil and gas sector and currently serves as the Head of Health, Safety, Environment, and Sustainability. Throughout his career, he has been actively involved in managing occupational safety and health systems within high-risk operational environments, where persistent challenges such as inconsistent safety behaviours, limitations of traditional safety management approaches, and gaps between formal safety systems and frontline practices were observed. These industry-driven challenges motivated his doctoral research, which focuses on integrates behavioural safety principles with digital technologies to address real-world safety culture gaps by enhancing engagement, accountability and safety behaviours. During his doctoral journey, he actively engaged in academic dissemination, including participation in two international conferences held in Bali, Indonesia, and Cairo, Egypt. He has produced 10 scholarly publications, of which 4 articles published, 1 accepted, while 5 additional manuscripts are currently under review in peer-reviewed journals. His work reflects a strong industry academia linkage, aiming to translate established safety culture theories into practical, technology-enabled solutions that are contextually relevant to the operational realities of the oil and gas industry.

LIST OF PUBLICATIONS

Published

Rahim, H., Dapari, R., Che Dom, N., & Mohd Noor, M. I. (2024). Decoding stakeholder priorities of safety culture preferences in the oil and gas industry. Scientific Reports, 14(1), 20735.

Rahim, H., Dapari, R., Osman, M. A., & Che Dom, N. (2026). A behaviourally informed digital framework for safety culture transformation in the oil and gas industry. *Scientific Reports*.

Rahim, H., Dom, N. C., Dapari, R., & Precha, N. (2023). A mapping review on safety culture in Malaysian industries: A research report from 2007 to 2022. *J. Sustain. Sci. Manag*, *18*(12), 136-150.

Rahim, H., Dapari, R., Dom, N. C., & Mohd Noor, M. I. (2025). Development and Validation of a Questionnaire on Safety Culture Elements Preference for Oil and Gas Industry. *Malaysian Journal of Medicine & Health Sciences*, *21*(5).

Rahim, H., Dom, N. C., & Dapari, R. (2025). Safety Culture Maturity Assessment: Insights and Improvement Opportunities for the Oil and Gas Sector. *Malaysian Journal of Medicine & Health Sciences*, *21*(5).

Accepted

Rahim, H., Dom, N. C., & Dapari, R. (2025). Developing A Real-Time Behavioural Safety Culture (BOSCA) Using Progressive Web Applications (PWA). *Malaysian Journal of Medicine & Health Sciences*, Accepted Aug 2025

Rahim, H., Dom, N. C., & Dapari, R. (2025). Developing A Real-Time Behavioural Safety Culture (BOSCA) Using Progressive Web Applications (PWA). *Malaysian Journal of Medicine & Health Sciences*, Accepted Aug 2025

Submitted

Rahim, H., Dom, N. C., & Dapari, R. (2026). Multidimensional Safety Culture and Its Influence on Safety Performance: Evidence from Structural Equation Modelling *International Archive of Occupational and Environmental Health*, Correction #1

Rahim, H., Dom, N. C., & Dapari, R. (2026). Do Mobile Apps Make Work Safer? Evidence and Gaps in Behavioural Safety Across High-Risk Settings. *International Archive of Occupational and Environmental Health*, Under Review

Rahim, H., Dom, N. C., & Dapari, R. (2026). Development and Expert-Based Content and Design Validation of the Behavioural Occupational Safety Culture Application (BOSCA). *Scientific Reports. Under Review*

Rahim, H., Dom, N. C., & Dapari, R. (2026). Bridging Human and Technological Dimensions: A Systematic Exploration of Safety Culture Transformation in the Oil and Gas Industry. *Humanities and Social Sciences Communications*. Under Review