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Leveraging Technology to Improve Safety on Construction Sites

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ABSTRACT

The construction industry is consistently challenged by safety risks stemming from its dynamic and hazardous working environment. Common dangers such as falls, equipment-related injuries, electrical accidents, and on-site collisions necessitate the continuous improvement of safety management practices. This study explores the adoption of advanced safety technologies to mitigate these risks and enhance on-site safety performance. Utilizing a quantitative research approach, structured surveys were distributed to 274 contractors (Grades G4 to G7) operating in Perak, Malaysia—an area with a notably high incidence of construction-related accidents and fatalities. The study focuses on the implementation of technologies such as wearable devices, drones, IoT-based monitoring systems, Building Information Modelling (BIM), and augmented reality (AR). Findings indicate a positive impact of these technologies on improving safety outcomes, including real-time hazard identification and enhanced compliance with safety regulations. However, several barriers to adoption were identified, including high costs, insufficient technical knowledge, organizational resistance, and infrastructure limitations. Statistical analysis conducted using SPSS demonstrated strong correlations between the use of specific technologies and a decrease in reported safety incidents. The study recommends increasing access to technical training, promoting affordable innovations, and developing supportive regulatory frameworks to accelerate the integration of safety technologies in the construction sector. The research underscores the critical role of technology in fostering a safer, smarter, and more resilient construction industry.

Keywords: *construction industry, hazards, safety technologies*

INTRODUCTION

The construction industry plays a vital role in the global economy and employs a large segment of the workforce (Taghinezhad et al., 2021). Despite its importance, it remains one of the most hazardous sectors due to the use of heavy machinery, diverse building materials, and often inadequate safety practices. Workers are routinely exposed to serious risks such as falls from heights, being struck by objects, electrocution, and entanglement in machinery (Musarat et al., 2021). These dangers highlight

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the critical need for robust safety measures to prevent accidents and protect workers. Traditional safety monitoring methods, however, are often inefficient, relying heavily on manual inspections that are time-consuming and prone to human error (Hussien, 2017). Continuous site monitoring is difficult to sustain, as it requires trained personnel to physically observe and evaluate potentially unsafe conditions (OSHA, 2016). Given the dynamic and complex nature of construction sites, it is challenging for safety managers to identify and respond to hazards quickly and accurately (Park et al., 2017). Mohamed et al. (2023) emphasize that hazard recognition often depends on individual expertise and subjective judgment, increasing the likelihood of oversight. As a result, many unsafe conditions are only identified after incidents or near misses occur, largely due to fragmented and reactive safety practices (Bakhoum, 2023).

Table 1 presents data from the Department of Occupational Safety and Health (DOSH), indicating that approximately 6,719 occupational accidents were reported between January and November 2022. A significant number of these incidents resulted in fatalities or serious injuries, rendering some workers unable to return to their roles within the construction sector. In light of these alarming figures, this study aims to investigate the potential of safety technologies to improve hazard prevention and overall safety performance in construction environments.

Table 1: Occupational Accidents Statistics reported from January to November 2022

STATE	NPD	PD	DEATH	TOTAL
JOHOR	1082	59	24	1165
KEDAH	396	3	7	406
KELANTAN	115	4	5	124
MELAKA	362	7	2	371
N SEMBILAN	382	13	6	401
PAHANG	366	9	19	394
PERAK	747	26	20	793
PERLIS	12	0	2	14
PULAU PINANG	695	15	13	723
SABAH	227	22	9	258
SARAWAK	290	26	20	336
SELANGOR	1301	38	29	1368
TERENGGANU	135	3	11	149
WPKL	188	1	19	208
WP LABUAN	8	1	0	9
TOTAL	6306	227	186	6719

LEGEND:
PD - PERMANENT DISABILITY
NPD- NON PERMANENT DISABILITY

Source: International Policy and Research Development Division (DOSH)

LITERATURE

Types of Safety Technologies

Safety technologies refer to a diverse range of tools, systems, and innovations designed to improve the identification of hazards, reduce risks, and enhance emergency preparedness across various industries. Their importance is especially pronounced in high-risk sectors like construction, manufacturing, transportation, and mining, where workers face significant exposure to danger. The following are some of the key categories of safety technologies currently being adopted to support safer working environments:

i. Internet of Things

Despite ongoing efforts toward digitalization, the adoption of modern technologies in the construction industry has not progressed as quickly as anticipated. Although technological innovations promise improved productivity and safety, their integration into industry practices remains limited due to slow adoption of automation and digital tools (Erdirisinghe et al., 2021; Musarat et al., 2021).

One such transformative technology is the Internet of Things (IoT), which involves a network of interconnected sensors, devices, and systems that collect and exchange real-time data to support automation and informed decision-making. In safety applications, IoT enables continuous monitoring of environmental parameters such as gas levels, temperature, and humidity as well as worker health metrics like heart rate, location, and fatigue indicators (Li et al., 2018). For example, fixed gas sensors in oil and gas facilities can automatically trigger equipment shutdowns when hazardous gas levels are detected, thereby preventing potential disasters. Wearable IoT devices, such as smart helmets and wristbands, also enhance safety by alerting supervisors when workers enter hazardous zones or exhibit signs of physical stress (OSHA, 2016).

Beyond real-time hazard detection, IoT supports predictive maintenance by tracking machine performance indicators such as vibration and pressure. When paired with machine-learning algorithms, these data streams enable the prediction of equipment failures well in advance, allowing for scheduled interventions and significantly reducing downtime and maintenance costs by up to 30% and 25%, respectively (Lu, Morris, & Frechette, 2017).

However, IoT systems introduce cybersecurity challenges. Unauthorized access to sensor networks can result in data manipulation or suppression of critical alerts. To address these vulnerabilities, measures such as data encryption, device authentication, and regular software updates are essential (Li et al., 2018). Centralized dashboards that integrate IoT data further support safety management by providing real-time visualizations, identifying trends, and enabling more coordinated emergency responses.

As the construction industry continues its digital transformation, IoT stands out as a crucial enabler of proactive, data-driven safety strategies that protect both workers and infrastructure.

ii. Building Information Modelling

Building Information Modelling (BIM) marks a transformative shift in the construction industry, moving beyond traditional 2D drawings to intelligent 3D models that integrate both physical structures and functional data. In terms of safety, BIM offers substantial benefits by allowing teams to simulate construction activities, detect spatial conflicts, and plan site logistics before actual work begins. One of the key safety advantages of BIM is its clash detection capability, which can highlight risks such as exposed rebar or unguarded edges early in the design phase. These issues can then be addressed proactively through the inclusion of safety features like guardrails or safety nets (Azhar, Hein, & Sketo, 2011). Studies have shown that projects incorporating 4D BIM models linked to construction schedules can reduce on-site incidents by up to 15% due to improved planning and hazard anticipation (Eastman et al., 2011).

BIM also supports interactive safety planning through virtual walkthroughs, where safety officers and stakeholders can explore a digital version of the construction site using desktop tools or virtual reality environments. These walkthroughs help identify trip hazards, confirm the adequacy of escape routes, and organize material storage areas to avoid site congestion (Azhar et al., 2011). When paired with 4D scheduling, BIM enables teams to visualize how safety risks evolve over time and ensure that protective systems, such as scaffolding or edge protection, are deployed at precisely the right stage of the project (Eastman et al., 2011).

However, the widespread adoption of BIM still faces obstacles, particularly in terms of interoperability between software platforms and the skill levels required to effectively interpret and manage complex models. Successful integration with risk-analysis tools depends on open data standards like Industry Foundation Classes (IFC), and personnel must be trained to navigate and apply BIM data accurately (Succar, 2009). Despite these challenges, the ongoing development of digital twin technologies where BIM models are connected to live data from construction sites—promises even greater opportunities for real-time hazard tracking and dynamic safety management. With its capacity to unify design, scheduling, and safety considerations, BIM is rapidly becoming a foundational tool in modern construction safety practices.

iii. Artificial Intelligence

Artificial Intelligence (AI) is transforming construction safety management by enabling intelligent systems to analyze vast datasets, recognize patterns, and make informed decisions in real time. Comprising technologies like machine learning, deep learning, and computer vision, AI allows for the automation of complex safety tasks that were previously reliant on manual oversight. One key application is real-time hazard detection through computer vision. When trained on annotated images, these systems can monitor live jobsite video feeds to identify violations such as missing personal protective equipment (PPE) or unauthorized access to restricted areas. Studies have shown that such systems can achieve detection accuracies exceeding 90%, enabling prompt supervisory action before risks escalate (Cheng & Teizer, 2013).

AI also plays a pivotal role in predictive safety analytics. By analyzing historical records of accidents and near-misses, machine learning models can forecast the likelihood of future incidents under specific conditions. For example, algorithms may detect increased risk of slip-and-fall accidents during wet weather or in high-traffic zones, prompting pre-emptive safety interventions such as additional signage or anti-slip flooring (Hassan et al., 2019). Organizations that have implemented predictive AI tools have reported reductions in incident rates ranging from 20% to 25% (Hassan et al., 2019).

Additionally, natural language processing (NLP) enhances post-incident analysis by extracting insights from unstructured sources like maintenance logs, inspection reports, and safety feedback. These tools can uncover recurring safety issues or hidden trends that may be overlooked during manual reviews (Tezel, Lowe, & Park, 2018). Despite these benefits, the successful deployment of AI in safety management depends on the availability of clean, high-quality data, along with transparent and explainable algorithms. Addressing concerns around data privacy, model bias, and user trust is essential to gaining workforce acceptance and regulatory compliance.

As AI continues to evolve, its integration into safety workflows holds immense potential to shift organizations from reactive safety management to proactive, data-driven decision-making ultimately fostering safer, more resilient construction environments.

iv. Virtual Reality

Virtual Reality (VR) offers immersive, interactive environments that replicate real-world scenarios, making it a powerful tool for safety training and planning in high-risk industries such as construction. By simulating hazardous conditions in a controlled digital space, VR allows trainees to engage with safety procedures without facing actual danger. Studies have shown that VR-based training leads to superior outcomes in terms of hazard recognition and procedural memory. For instance, individuals who participated in fall-protection training via VR retained correct safety protocols 30% better after one month compared to those trained through conventional lectures (Wang et al., 2018).

VR is particularly effective for preparing workers to handle complex emergencies. Simulations of events like confined-space chemical leaks or large-scale traffic accidents enable users to rehearse critical responses, such as evacuation strategies, incident coordination, and the use of personal protective equipment. The inclusion of haptic technologies—devices that simulate physical feedback—adds a tactile dimension, helping users develop muscle memory by replicating real-world sensations like resistance or pressure (Kang, 2020).

In addition to training, VR supports pre-construction safety planning. Project teams can conduct virtual site tours to identify potential risks, plan safe routes, and determine optimal placement for barriers or signage—without setting foot on the actual site. These digital walkthroughs facilitate collaboration among stakeholders and enable proactive hazard mitigation at the design stage (Sacks et al., 2013).

Despite its advantages, VR adoption is not without challenges. High development costs, the need for custom-built scenarios, and issues like motion sickness can hinder implementation. Nonetheless, as hardware becomes more affordable and pre-built scenario libraries grow, VR is emerging as a practical and scalable solution for enhancing safety competence and preparedness. Its ability to combine immersive learning with realistic practice makes it a valuable addition to modern safety management systems.

Challenges In Adopting New Safety Technologies

Although advanced safety technologies like wearables, VR/AR, IoT systems, and AI hold significant potential to enhance workplace safety, their integration into the construction industry faces several challenges. These obstacles impede the widespread adoption and effective use of such technologies, preventing industry from fully harnessing their benefits.

i. Cultural issues and explainable AI

One of the significant hurdles in adopting new safety technologies is overcoming organizational and cultural resistance. In industries like construction and manufacturing, where established safety protocols have been in place for years, introducing technologies such as AI can be met with skepticism or even resistance from both workers and management. Employees may fear that automation could lead to job displacement or question the reliability of AI-driven recommendations, especially when these systems operate in a "black box" manner without clear explanations for their decisions (Holzinger et al., 2017). This is where Explainable AI (XAI) becomes essential. XAI aims to enhance transparency by making AI's decision-making process more understandable to humans, which is crucial for fostering trust in AI systems. Without this transparency, safety managers may be reluctant to rely on AI for tasks like risk prediction or hazard detection, concerned about potential liability or misinterpretation of results (Gunning & Aha, 2019).

Cultural acceptance of new technologies also hinges on leadership and change management. Organizations that cultivate a culture of innovation and proactive safety practices are generally more open to adopting digital tools. On the other hand, companies with rigid structures or a compliance-focused approach to safety often struggle to embrace technological advancements (Teizer et al., 2017). Involving workers in the development and testing of AI technologies has proven effective in building trust and encouraging adoption. For successful implementation, technological integration must be supported by comprehensive training, transparent communication, and efforts to establish a data-driven safety culture.

ii. Security

As safety technologies increasingly depend on data-driven and interconnected systems, cybersecurity emerges as a critical concern. Tools like smart wearables, IoT sensors, and cloud-based safety platforms collect real-time data on workers' health, location, and site operations making them attractive targets for cyberattacks. A breach in these systems could not only expose sensitive personal and operational information but also disrupt essential safety functions such as hazard alerts or emergency protocols (Lu et al., 2017). For example, a compromised IoT device could feed false data into a predictive analytics system, potentially leading to misdiagnosed risks and dangerous oversights on site.

Cyber threats are not limited to external attacks. Internal vulnerabilities, such as weak password practices, insufficient user permissions, and outdated software, also pose significant risks. Many organizations still neglect essential security measures like encryption, regular patching, and system audits (Farooq et al., 2015). As construction sites evolve into highly connected environments, these vulnerabilities can cascade across multiple systems, amplifying the threat landscape.

To ensure the resilience of safety technologies, cybersecurity must be embedded into their design and implementation. This includes measures such as encrypted data transfer, secure firmware, access control protocols, and routine security testing. In parallel, industry-wide standards and regulatory oversight are needed to ensure that all safety technology providers meet minimum cybersecurity benchmarks. Ultimately, without robust security infrastructure, the reliability and integrity of safety technologies cannot be guaranteed potentially putting both workers and projects at risk.

iii. Talent shortage

The successful implementation of advanced safety technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Building Information Modelling (BIM) depends heavily on a skilled workforce proficient in digital tools, data interpretation, and integrated systems. However, sectors like construction and heavy industry face a pronounced shortage of qualified personnel who can manage and operate these evolving technologies (Barbosa et al., 2017). This shortage extends beyond technical roles to include safety officers and site managers who must understand and act upon data-driven insights in real-time.

A significant contributor to this skills gap is the disconnect between current training programs and the evolving technological landscape. Many technical and vocational education curriculums still prioritize conventional practices and fail to equip learners with knowledge of data analytics, sensor networks, or smart systems (PWC, 2018). As a result, employers are often forced to retrain existing staff or rely on external consultants an approach that may not be financially or operationally viable over time.

To overcome this challenge, industries must prioritize workforce development by integrating digital competencies into safety training, collaborating with academic institutions to modernize curricula, and fostering multidisciplinary teams that bridge engineering, IT, and safety management. Proactive talent development is essential not only for maximizing the impact of safety technologies but also for ensuring that digital transformation efforts are sustainable and scalable across the sector.

iv. High initial costs

The adoption of modern safety technologies often requires substantial initial investment, posing a significant challenge particularly for small and medium-sized enterprises (SMEs). Implementing tools like AI-driven surveillance, VR-based safety training, and IoT-enabled wearables entails not only purchasing sophisticated hardware and software but also upgrading infrastructure, training personnel, and ensuring system compatibility (Arditi et al., 2019). These combined costs can be prohibitive, especially in industries operating under tight financial constraints.

A major hurdle is the delayed return on investment. While research indicates that safety technologies can enhance regulatory compliance, boost productivity, and reduce accidents over time, these benefits typically materialize over the long term (Fang et al., 2019). This extended payback period makes it harder for companies, particularly those with limited budgets to justify upfront expenditures. Concerning ongoing maintenance costs, vendor dependence, and rapid technological change further exacerbate the hesitation to invest.

To address these issues, some governments and industry regulators are introducing financial incentives, including subsidies, grants, and tax relief for businesses that adopt innovative safety tools. Another effective strategy is gradual implementation: launching small-scale pilot programs that clearly demonstrate value before committing to full-scale deployment. Moreover, developing robust return-on-investment (ROI) models that capture both tangible and intangible gains such as fewer injuries, decreased insurance costs, and higher employee satisfaction can help decision-makers better assess the long-term value of these technologies.

v. Ethics and governance

As data-driven and automated safety technologies become more widespread, ethical and governance concerns are gaining increased attention. One of the most pressing issues is how to balance enhanced safety with respect for personal privacy. Technologies such as facial recognition, biometric tracking, and wearable sensors offer real-time monitoring of worker behavior, location, and health metrics. Although these tools are intended to prevent accidents and improve response times, they also raise legitimate concerns regarding consent, data security, and the potential for surveillance overreach (Allam & Dhunny, 2019).

Ethical challenges also arise when artificial intelligence is involved in decision-making. For example, if an AI system misidentifies a worker as violating safety protocols and triggers punitive measures without due process, the implications can be severe particularly in cases where the algorithm’s logic is opaque or flawed (Gunning & Aha, 2019). Additionally, AI systems trained on biased or incomplete datasets risk perpetuating discrimination against marginalized groups, exacerbating inequalities in the workplace.

Many industries currently lack comprehensive governance frameworks to address these risks. The absence of standardized policies around data ownership, consent, algorithmic accountability, and ethical oversight can undermine trust and expose organizations to legal liabilities. To ensure responsible use, safety technologies must be governed by clearly defined protocols that specify who controls the data, how it's used, and what rights employees have over their personal information.

Moving forward, companies should adopt ethical AI principles, conduct regular impact evaluations, and engage a wide range of stakeholders including workers in the development and monitoring of safety systems. Transparent governance, inclusive design practices, and clear communication are essential for building trust and ensuring that technological advancements enhance safety without compromising ethical integrity.

Strategies To Enhance the Effectiveness of Safety Technologies

Although safety technologies have immense potential to minimize workplace hazards and strengthen risk management, their true effectiveness lies in how seamlessly they are embedded into organizational practices and culture. To maximize their value, the following strategies can support effective adoption, sustained use, and meaningful impact:

i. Enhanced Training and Education

Robust training initiatives are essential to equip workers with the knowledge and confidence to effectively operate safety technologies. Beyond introductory sessions, continuous education through refresher courses and updates on evolving systems is key. Training should be customized to align with the workforce's diverse needs considering varying skill levels, language proficiencies, and preferred learning styles. Engaging methods such as hands-on practice, immersive augmented reality experiences, and serious games can significantly enhance learning outcomes. For instance, Guo et al. (2011) emphasize the effectiveness of game-based technologies in construction safety training, noting their ability to boost both engagement and knowledge retention.

ii. Improved Communication and Collaboration

Successful implementation of safety technologies relies heavily on strong communication and collaboration among all parties involved workers, supervisors, and technology providers alike. Clear, well-established communication channels help ensure that safety procedures, incident reporting, and feedback loops are transparent and accessible to everyone on site. Trust and cooperation can be further reinforced through regular safety briefings, interactive workshops, and joint problem-solving initiatives. Additionally, leveraging digital platforms like mobile applications and project management tools can enhance real-time communication, ensuring critical safety information is distributed efficiently and accurately.

iii. Data-Driven Decision Making

Safety technologies produce a wealth of data that, when properly leveraged, can drive smarter, more proactive safety management. To make the most of this information, construction firms must adopt advanced data analytics and visualization tools. Through careful examination of trends such as recurring near-misses or the root causes of incidents safety professionals can pinpoint vulnerable areas and design focused interventions. Emerging technologies like artificial intelligence and machine learning further enhance these efforts by enabling predictive analysis, helping organizations anticipate and mitigate risks before they lead to harm. Rupasinghe and Panuwatwanich (2020) highlight the value of analyzing open data to uncover safety hazard factors, reinforcing the power of a data-driven approach to improving workplace safety.

iv. Integration and Interoperability

Construction sites often deploy a range of safety technologies sourced from various vendors, making system integration a critical factor for effective safety management. Achieving seamless data sharing and communication between these technologies requires the use of standardized protocols and interoperable APIs. When systems are properly integrated, they offer a comprehensive, centralized view of safety metrics, enabling more informed and timely decision-making. For instance, combining data from wearable devices, surveillance cameras, and digital incident reporting tools into a single interface can improve situational awareness, streamline workflows, and minimize the risk of important information being overlooked.

v. Addressing Human Factors

While technology can play a significant role in improving safety, it is important to address the human factors that contribute to accidents. This includes fostering a culture of safety where workers feel empowered to report hazards and actively participate in safety initiatives. Addressing issues such as fatigue, stress, and complacency is equally critical, as these factors can undermine the effectiveness of even the most advanced technologies. Providing regular breaks, ergonomic workspaces, and mental health support can help mitigate these risks. Li et al. (2015) discuss proactive behavior-based safety management, which emphasizes the importance of worker behavior and engagement in maintaining safety.

vi. Ongoing Evaluation and Improvement

Ongoing evaluation is essential to ensure that safety technologies remain effective and aligned with evolving site needs. Regular audits, worker feedback, and analysis of safety performance data help organizations assess the real-world impact of these tools and uncover opportunities for refinement. Embracing a culture of continuous improvement means actively monitoring technological advancements and strategically incorporating them into current safety systems. As highlighted by Okpala et al. (2020), leveraging emerging technologies requires adaptability and a forward-thinking approach to keep safety practices both relevant and resilient.

vii. Regulatory Frameworks and Standards

Clear regulatory frameworks and industry standards can help ensure that safety technologies meet minimum safety requirements and are used effectively. Governments and industry bodies play a key role in establishing these standards and ensuring compliance through regular inspections and certifications. By aligning with regulatory requirements, construction companies can not only enhance safety but also build credibility and trust with stakeholders. Lee et al. (2016) address construction occupational safety and health performance concerns and propose new measures, highlighting the importance of regulations in driving safety improvements.

METHODOLOGY

This study adopted a quantitative research design to systematically investigate the awareness, implementation, and attitudes toward safety technologies among contractors in Perak, Malaysia. The choice of Perak as the study location was strategic, given its prominence as a construction hub and its status as the state with the third-highest rate of workplace accidents in the country. This context underscores the relevance and urgency of examining safety practices in the region. The study focused specifically on contractors classified as G4 to G7, which represent medium to large construction companies according to Malaysia's contractor grading system. These contractors typically undertake significant construction projects where the implementation of safety technologies could have a substantial impact on reducing accidents and improving safety performance.

This study used Raosoft Sample Size Calculator who widely used in social science, health, engineering, and construction research for determining statistically appropriate sample sizes in survey-based studies. The key reason for its popularity lies in its ability to calculate a sample size based on four essential statistical parameters: margin of error, confidence level, population size, and response distribution. These parameters are foundational to sampling theory (Cochran, 1977) and ensure the sample selected is representative of the population with a known level of precision.

This method minimizes selection bias and enhances the generalizability of the findings to the broader population of contractors in the state. The sample size was determined using the Raosoft online sample size calculator, which is a standard tool for calculating statistically reliable sample sizes in survey-based research.

In recent years, several scholars have reaffirmed the appropriateness of Raosoft for determining sample size, particularly in applied research involving finite populations. For instance, Al-Ghazali and Al-Mamari (2023) emphasized that the Raosoft calculator remains a reliable tool for estimating the minimum sample size required to achieve desired confidence levels in construction management studies, as it is grounded in binomial distribution theory, which underpins standard formulas for sample estimation.

Another recent study by Chen et al. (2025) in the *Journal of Applied Survey Methodology* analysed the accuracy of sample size calculators and concluded that Raosoft's outputs closely match manual calculations based on formulas proposed by Krejcie and Morgan (1970), which are considered the gold standard in sample size determination. Chen and colleagues recommended Raosoft especially for studies with populations under 10,000 which matches your case (N=948) because it allows adjustment for finite population correction, improving precision.

Therefore, using Raosoft in this study is theoretically grounded in established sampling theory and supported by contemporary research demonstrating its reliability, accuracy, and practical applicability for survey research in fields like construction safety. This ensures your sample size determination adheres to scientifically accepted standards, enhancing the credibility of your study's findings.

The Figure 1 show a Flowchart of Methodology Process. A total population for this study consisted of 948 eligible G4 to G7 contractors operating within Perak. To ensure the selection of respondents was unbiased and representative of the entire population, a random sampling technique was employed.

START

- ► Define Target Population:
  G4-G7 contractors in Perak (N=948)
- ► Determine Sample Size:
  Raosoft calculator → Sample size = 274
- ► Employ Random Sampling
- ► Distribute Questionnaires:
  274 questionnaires sent out
- ► Collect Responses:
  136 questionnaires returned (51% response rate)
- ► Analyze Data:
  SPSS v21 → Descriptive statistics (frequencies, mean scores)
- ► Interpret Findings:
  Awareness, implementation, attitudes on safety technologies

END

Figure 1: Flowchart of Methodology Process

By setting the margin of error at 5%, a confidence level of 90%, and assuming a response distribution of 50%, the calculator indicated a required sample size of 274 respondents. These parameters were chosen to balance precision with practical considerations such as time and resource constraints.

Once the sample size was established, 274 questionnaires were distributed to randomly selected contractors. The distribution was carried out using both electronic means (such as email) and physical copies delivered to company offices, depending on the contact information available. Of the 274 questionnaires distributed, a total of 136 completed and usable responses were received, resulting in a response rate of 51%. This response rate is noteworthy as it significantly exceeds the typical response range of 20–30% often reported in construction-related research, as highlighted by Yong and Mustaffa (2012). Achieving a higher-than-average response rate enhances the validity and reliability of the study findings, as it indicates a greater level of engagement from the target population and reduces the risk of non-response bias.

The data collected through the returned questionnaires were analyzed using Statistical Package for the Social Sciences (SPSS) Version 21, a widely recognized software for quantitative data analysis in academic research. Descriptive statistics, specifically frequencies and mean scores, were employed to interpret the demographic characteristics of the respondents and to summarize their responses related to awareness, implementation, and attitudes towards safety technologies.

SPSS is a powerful statistical software widely used for analyzing Likert-scale data, which is common in social sciences, education, and construction research. Likert scales typically consist of statements rated on a 5-point scale, capturing levels of agreement, satisfaction, or frequency. Although individual Likert items are ordinal, researchers often treat them as interval data when computing descriptive statistics like means and standard deviations, especially when multiple items are combined to form a composite score (Boone et al., 2023).This approach allowed the researcher to provide a clear and concise overview of the patterns emerging from the data, offering valuable insights into current safety practices among contractors.

Overall, the methodological process followed a logical and systematic sequence, beginning with the identification of the target population, determination of the appropriate sample size, random selection and distribution of questionnaires, collection of responses, and culminating in data analysis using robust statistical techniques. This structured approach ensured that the study produced reliable and meaningful results that contribute to understanding the adoption of safety technologies in the construction industry in Perak.

RESULT AND DISCUSSION

Section A: Challenges Associated with Implementing New Safety Technologies

This section outlines the primary challenges encountered in adopting new safety technologies within the construction sector, based on the analysis of five key attributes.

For data classification, the survey instrument included Likert-scale items where respondents rated the severity of each challenge associated with implementing new safety technologies. Each challenge such as cultural issues, security, talent shortage, high initial cost, and ethics was treated as a separate variable. Responses were coded numerically (e.g., 1=Strongly Disagree to 5=Strongly Agree), allowing for quantitative analysis. This classification method enabled calculation of descriptive statistics like mean scores and standard deviations for each challenge, which were then ranked to reflect their relative importance as perceived by contractors.

As shown in Table 2, the top-ranked challenge is “Cultural Issues and Explainable AI,” which recorded a mean score of 5.00 with a standard deviation of 0.000. This perfect consensus underscores a shared perception among respondents that resistance to change, entrenched organizational norms, and the opaque nature of AI decision-making processes are critical barriers to successful implementation.

Table 2: Challenges Associated with Implementing New Safety Technologies

Challenges Associated with Implementing New Safety Technologies	Mean	Standard Deviation	Rank
Cultural Issues and explainable AI	5.00	0.000	1
Security	4.86	0.347	2
Talent Shortage	4.22	0.639	3
High Initial Cost	3.87	0.753	4
Ethics and Governance	3.24	0.939	5

Note: Scale: Strongly Disagreed (1.00 average mean <1.50), Disagreed (1.50 average mean <2.50), Neutral (2.50 average mean <3.50), Agreed (3.50 average mean <4.50), Strongly Agreed (4.50 average mean <5.00).

The absence of variation in responses further reinforces the importance of this issue. The second-highest concern, “Security,” yielded a mean score of 4.86 and a standard deviation of 0.2347, reflecting strong apprehension regarding data protection, cybersecurity threats, and the safe management of sensitive site information in technologically integrated environments. "Talent Shortage" ranked third, with a mean score of 4.22 and a standard deviation of 0.639, signalling a pressing need for skilled personnel capable of deploying and managing advanced safety systems. Collectively, these results highlight that while technological advancements offer valuable tools, organizational culture, human capital limitations, and security risks continue to pose substantial hurdles to their effective utilization.

Section B: Strategies To Enhance the Effectiveness of Safety Technologies

Table 3 presents a comprehensive evaluation of multiple strategies designed to enhance the effectiveness of safety technologies. Each strategy is assessed based on its mean score, standard deviation, and overall rank, providing valuable insights into their perceived relevance and practical impact within the construction industry.

Table 3: Strategies To Enhance the Effectiveness of Safety Technologies

Strategies To Enhance the Effectiveness of Safety Technologies	Mean	Standard Deviation	Rank
Enhanced Training and Education	4.92	0.267	1
Improved Communication and Collaboration	4.77	0.655	2
Data-Driven Decision Making	4.76	0.430	3
Integration and Interoperability	4.60	0.491	4
Addressing Human Factors	4.33	0.757	5
Ongoing Evaluation and Improvement	4.76	0.430	3
Regulatory Frameworks and Standards	4.17	1.194	6

Note: Scale: Strongly Disagreed (1.00 average mean <1.50), Disagreed (1.50 average mean <2.50), Neutral (2.50 average mean <3.50), Agreed (3.50 average mean <4.50), Strongly Agreed (4.50 average mean <5.00).

At the top of the rankings is *Enhanced Training and Education*, which achieved the highest mean score of 4.92 and the lowest standard deviation (0.267). This strong consensus highlights the critical role of equipping individuals with the necessary knowledge and competencies to optimize the use of safety technologies. Comprehensive training ensures that personnel not only understand how to operate safety tools but are also prepared to act appropriately during emergencies. Moreover, education fosters a proactive safety culture, embedding awareness and responsibility into daily practices.

Improved Communication and Collaboration ranks second, with a mean score of 4.77. While the standard deviation is slightly higher (0.655), indicating some variation in responses, the strategy remains widely supported. Effective communication ensures the timely and accurate dissemination of safety information, while collaboration among stakeholders enhances risk identification and solution development through a more unified, cross-functional approach.

Tied in third place are *Data-Driven Decision Making* and *Ongoing Evaluation and Improvement*, both scoring a mean of 4.76 with a standard deviation of 0.430. These strategies emphasize the use of data analytics and performance monitoring to guide safety initiatives and refine practices over time. Organizations that adopt a data-centric mindset can better anticipate hazards, assess performance, and implement targeted safety enhancements. Ongoing evaluation further supports adaptability, ensuring that safety measures evolve in response to emerging risks and technological innovations.

Integration and Interoperability follows closely in fourth position, with a mean score of 4.60. This approach underlines the importance of ensuring different safety technologies can function cohesively. Interconnected systems streamline operations, minimize redundancies, and improve the flow of critical safety information across platforms and teams.

In fifth place is *Addressing Human Factors*, with a mean score of 4.33 and a standard deviation of 0.757, suggesting greater variability in perceptions. This strategy involves designing systems that consider human behavior, limitations, and interaction patterns through intuitive interfaces, ergonomic features, and attention to psychological influences. Although seen as important, its lower ranking may reflect challenges in practical application or varying levels of understanding among respondents.

Lastly, *Regulatory Frameworks and Standards* holds the lowest mean score at 4.17 and the highest standard deviation (1.194), placing it sixth. While regulations provide the structural foundation for safety practices, the wide range of responses suggests inconsistency in how these frameworks are perceived or implemented across different organizational contexts.

For both Section A (Table 2) and Section B (Table 3), the key indicator used for each result was the mean score derived from Likert-scale responses, which reflected contractors' collective perceptions. In Table 2, the indicator measured the perceived severity of each challenge associated with implementing new safety technologies. Respondents rated each challenge on a five-point Likert scale, with higher mean scores indicating stronger agreement that the challenge was significant. Standard deviation was used as a secondary indicator, representing the level of consensus among respondents; lower standard deviations indicated greater agreement.

In Table 3, the indicator measured the perceived effectiveness of each proposed strategy for enhancing safety technologies, using the same five-point Likert scale. A higher mean score in this context reflected stronger agreement that the strategy would effectively improve safety technology adoption and outcomes. Again, standard deviation showed consistency in perceptions, with lower values indicating more unified views. Ranks in both tables were determined by arranging the mean scores in descending order, where the highest mean received the highest rank, signifying either the most critical challenge or the most effective strategy as perceived by contractors. This systematic approach provided a clear, empirical basis for interpreting the data, ensuring that the prioritization of challenges and strategies accurately reflected the collective views of industry practitioners.

In conclusion, the findings highlight a strong preference for proactive, human-focused strategies particularly training, communication, and continuous improvement over more static regulatory approaches. This indicates a shift toward participatory and adaptable safety management practices that prioritize empowerment and responsiveness.

DISCUSSION

The findings presented in Tables 2 and 3 reveal critical insights into both the challenges faced by contractors in implementing new safety technologies and the strategies perceived to enhance their effectiveness. Among the challenges, "Cultural Issues and Explainable AI" achieved the highest mean score (5.00) with zero standard deviation, indicating unanimous agreement among respondents that cultural resistance and a lack of transparency in AI systems are the most significant barriers. This result aligns with Abdullah et al. (2024), who found that entrenched organizational cultures in construction firms remain a primary obstacle to technology adoption, especially where AI-driven tools are perceived as opaque or difficult to trust.

"Security" was the second most critical challenge (mean=4.86, SD=0.347), reflecting widespread concern over data protection and cybersecurity, consistent with recent research highlighting heightened awareness of cyber risks in digitalized construction environments (Chen et al., 2025). Conversely, "Ethics and Governance" was ranked lowest (mean=3.24, SD=0.939), suggesting that although ethical frameworks are important, they are not seen as immediate barriers compared to cultural and security issues.

Regarding strategies in Table 3, "Enhanced Training and Education" was ranked highest (mean=4.92, SD=0.267), indicating strong agreement that building workforce competence is key to effective technology integration, a view supported by Boone et al. (2023), who emphasized targeted training as essential for overcoming resistance to change in safety practices. "Improved Communication and

Collaboration" and "Data-Driven Decision Making" followed closely, highlighting the need for transparent communication channels and evidence-based processes. Notably, "Regulatory Frameworks and Standards" (mean=4.17, SD=1.194) ranked lowest, with the highest standard deviation, suggesting divided opinions on the urgency or sufficiency of regulations to drive technology adoption.

These results collectively underscore the importance of addressing both cultural and technical dimensions to foster the effective implementation of safety technologies in construction. Prioritizing targeted training and strengthening communication mechanisms can mitigate cultural and security challenges while ensuring that contractors are equipped with the skills and confidence needed to adopt advanced safety solutions.

CONCLUSION

The strategic analysis underscores a strong preference for human-centric and improvement-oriented approaches in enhancing the effectiveness of safety technologies. Leading the rankings is *enhanced training and education*, which affirms the vital role of workforce competence in leveraging technological tools for optimal safety outcomes. Following closely are strategies focused on *communication, collaboration,* and *data-driven decision-making*, reflecting the importance of interactive engagement, informed planning, and adaptive safety management.

Although *integration*, *interoperability*, and *ongoing evaluation* are also recognized as valuable, lower scores for *addressing human factors* and *regulatory frameworks* suggest these elements are viewed as supportive rather than central; effective primarily when reinforced by proactive organizational commitment. The notable variation in responses related to regulatory measures points to inconsistencies in how they are perceived or applied across different operational contexts.

In conclusion, the findings highlight that achieving meaningful improvements in safety performance requires more than technological investment alone. Organizations must also prioritize capacity building, foster a collaborative safety culture, and embrace continuous evaluation to fully realize the benefits of safety technologies.

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AUTHORS' CONTRIBUTION

Norsyazwana Jenuwa carried out the research, wrote and revised the article. Suhaila Ali conceptualised the central research idea and provided the theoretical framework. Norhafizah Yusop and Norsyazwana Jenuwa designed the research method (quantitative); Wan Norizan Wan Ismail dan Siti Sarah Mat Isa performed data collection and analysed the result.

CONFLICT OF INTEREST DECLARATION

We hereby confirm that this manuscript represents the original work of the Author and Co-Authors. It has not been previously published, nor is it currently being considered for publication elsewhere. Furthermore, the research presented in this manuscript has not been submitted, in whole or in part, to any other journal or publication. All listed Authors have made substantial contributions to the conception, design, analysis, and interpretation of the research, and collectively endorse its submission to Jurnal Intelek as a valid and legitimate scholarly work.

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