

Study on RFID Implementation on Safety Vest for Real-time Human Safety Prevention in Construction Sites

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Abstract

Safety remains a significant issue in the construction industry, particularly in Malaysia, where high accident rates persist. Implementing RFID technology in safety vests offers a proactive approach to real-time risk monitoring, potentially transforming safety protocols on construction sites. This study aims to investigate the implementation of RFID on safety vests for real-time worker safety prevention in the construction site. Therefore, the objectives of this study are to investigate the potential, challenges, and strategies to promote RFID implementation on safety vests for real-time human safety in construction sites. A qualitative research methodology was used, combining primary data from semi-structured interviews with individuals in Malaysia, such as a technical executive, a founder, a business development manager, a government agency representative, and a site safety supervisor. Respondents are selected based on their extensive expertise and comprehensive experience in the utilization of RFID systems. Secondary data is sourced from books, academic journals, conference proceedings, and other credible publications. Content analysis was applied to examine the potential and challenges of RFID technology in safety vests for real-time safety monitoring. The study found that RFID could enhance incident response by alerting workers when they approach hazardous areas. However, resistance from workers in adapting to new technologies, such as RFID, emerged as a significant challenge. To address this, the study identified education and training programs as the most effective strategy for facilitating RFID adoption. In conclusion, RFID-enabled safety vests hold great potential to improve safety on construction sites, and overcoming worker resistance through comprehensive education and training is essential for successful implementation.

1. Introduction

The traditional manual management method cannot address the issue of frequent accidents in the engineering construction process. This is because conventional safety management requires significant resources, including workforce, materials, and finances, and is ineffective in preventing hidden safety hazards during construction (Binyong *et al.*, 2018). Radio Frequency Identification (RFID) technology emerges as a potential solution, offering real-time data collection and automated safety protocols that can significantly enhance existing safety

management practices. Hence, Nnaji & Karakhan (2020) stated that adopting and implementing innovative solutions is an effective way to boost construction safety performance. This research heavily relies on emerging technologies and information and communication technology. RFID is one of the technologies that can be applied to improve safety in the construction industry. RFID refers to technologies using radio waves to identify people or objects automatically. There are several methods of identification, the most common of which is to match the RFID tag's unique identifier to an object or person. The primary benefits of an RFID system are its non-contact, non-line-of-sight capabilities. Tags can be read under various visually and environmentally challenging conditions, including snow, ice, fog, paint, grime, inside containers and vehicles, and while in storage (Roberts, 2006). RFID technology uses radio waves to automatically recognize physical objects. It is an example of automatic identification (Auto-ID) technology, which identifies physical objects automatically (Lahiri, 2006). In this study, the RFID tag will be placed on the safety vest to detect objects that have been struck nearby and to issue an alarm to warn the worker of danger nearby.

Traditional methods struggle to manage risks and prevent accidents due to resource limitations and blind spots. This research highlights RFID technology as a powerful tool to revolutionize safety practices. By embedding RFID tags within safety vests, workers gain real-time hazard detection. The RFID system can identify approaching dangers and trigger alarms, empowering workers to react swiftly and avoid potential accidents. This innovative approach aligns perfectly with the industry's push for continuous improvement and aligns with the recommendation by Nnaji & Karakhan (2020) to embrace creative solutions for enhanced safety performance. In addition, RFID-equipped safety vests represent a significant leap forward in construction safety. This technology offers a cost effective, automated solution to protect workers and create a healthier, safer work environment. Therefore, this seeks to study RFID implementation on safety vests for real-time human safety prevention on the construction site. Unsafe construction sites will result in injuries, lost productivity, delays in work progress, medical expenses, and a negative impact on the company's reputation. Despite remarkable improvements in health and safety performance for reducing safety risks on construction sites through awareness, rules, regulations, and specifications, as well as interactive solutions, the number of injuries remains unusually high. High construction accident trends show that there is still a critical need to improve solutions to protect the health and safety of on-foot workers at construction sites (Minchuk *et al.*, 2009). Due to its high rates of accidents and fatalities, the construction sector has a high reputation for being among the riskiest (Zou, 2010).

Although RFID technology has received a lot of attention for its potential and benefits in improving safety on construction sites, the construction industry is not utilizing it effectively enough (Wu *et al.*, 2010). Despite the promising capabilities of RFID technology, Wu *et al.* (2010) point out a crucial gap between potential and practice. The construction industry is not yet fully capitalizing on the safety benefits that RFID offers. This underutilization could be due to factors like a lack of awareness about technology, concerns over initial investment costs, or even resistance to change within traditional safety management practices. Addressing these barriers and promoting wider adoption of RFID-enabled safety vests is essential to maximize their positive impact on worker safety in construction. Promoting wider adoption requires comprehensive training and education programs for workers and management on the functionalities and benefits of RFID-enabled safety vests. This can help overcome Resistance to change and ensure proper utilization of technology. While RFID technology offers a promising solution with its real-time hazard detection capabilities, Wu *et al.* (2010) identify a critical gap in which the industry is not fully utilizing this potential. To close the gap, the causes of the underutilization of safety vests with RFID capabilities must be addressed. These could include a lack of awareness, cost concerns, or resistance to change. Overcoming these barriers is crucial to maximizing the positive impact of RFID on worker safety. By promoting wider adoption of this technology, it can create a significant shift towards a safer construction industry. Equipping workers with RFID-enabled vests can empower them to react swiftly to approaching dangers, preventing accidents, injuries, and fatalities. This not only protects workers but also boosts productivity, reduces project delays, and improves a company's reputation. In addition, it's imperative to embrace innovative solutions like RFID and create a culture of safety awareness within the construction industry. This will ultimately lead to a healthier and safer work environment for all. Therefore, this study objectives to investigate the potential of RFID implementation on safety vests, identify the challenges of deploying RFID on safety vests, and establish strategies on promoting RFID on safety vests for real-time human safety prevention in construction sites.

2. Literature Review

2.1 Radio Frequency Identification (RFID) Technology

RFID, or Radio Frequency Identification, uses electromagnetic fields to automatically identify and track tags attached to objects. The tags hold electronically stored information that can be read from up to several meters away (Cecchi *et al.*, 2024). Radio-frequency identification technology provides several benefits, including

durability, which ensures RFID tags function properly in harsh environments where barcodes may fail. These features make RFID an effective tool for a variety of applications in logistics, retail, and beyond.

2.2 How RFID Functions

A radio device known as a tag is attached to the object that needs to be identified. This tag stores unique identification data for the tagged object. When a tagged object is placed in front of an RFID reader, the tag transmits the data to the reader (via the reader antenna). The reader then reads the data and can send it to a software application running on a computer via appropriate communication channels such as a network or serial connection. This application can then use the unique data to identify the object shown to the reader. It can then perform a variety of actions, including sending an alert to the floor personnel (Lahiri, 2006). Two important components that are implemented in this RFID study are the tag and the reader.

2.2.1 RFID Tags

An RFID tag is a device that can store and transmit data to a reader in a contactless manner via radio waves. Tags can be passive or active, depending on the context. Passive tags are RFID tags that do not have an on-board power source (such as a battery) and instead use the power emitted by the reader to energize themselves and transmit stored data to the reader. This tag is long-lasting and resistant to harsh environmental conditions. Meanwhile, active tags have an on-board power source (for example, a battery; alternative sources of power, such as solar, are also possible) and electronics for performing specialized tasks, and they use their on-board power supply to transmit data to a reader. The onboard electronics may include microprocessors, sensors, and input/output ports powered by the onboard power source. As a result, these components can measure the ambient temperature and produce average temperature data (Lahiri, 2006).

2.2.2 RFID Reader

The interrogator is another name for an RFID reader, which consists of a radio frequency interface (RFI) module and a control unit. The reader's primary responsibility is to activate the tag, establish a communication sequence, and transfer the tag's data to the application software. The reader is responsible for initiating communication with any tags that are within reading range, as well as providing the tag's data to programs that can use it. Furthermore, they can identify and read many tags per second with ease (Castro & Wamba, 2007).

2.3 Potential of RFID Implementation on Safety Vest for Real-Time Human Safety Prevention

2.3.1 Improved Incident Response

Radio Frequency Identification (RFID) has significant potential for real-time human safety management on construction sites. It allows for real-time tracking of workers, ensuring their safety by monitoring their movements and locations on-site, particularly in hazardous areas. The technology can also help to speed up the rescue process for injured workers by providing emergency responders with their exact location. Furthermore, RFID can be integrated with safety vests to improve visibility and traceability, which is critical for maintaining a safe workplace and lowering the risk of accidents. Overall, incorporating RFID into safety vests is a proactive approach to improving safety management in the construction industry (Lim *et al.*, 2022).

2.3.2 Automated Hazard Alert

RFID technology, when implemented on safety vests, has significant potential for real-time human safety management on construction sites, particularly automated hazard alerts. By embedding RFID tags in safety vests, the system can track workers' real-time location and automatically send alerts if they enter hazardous zones or if a potential danger arises. This proactive approach improves safety by issuing immediate warnings, reducing emergency response times, and potentially preventing accidents before they occur (Lim *et al.*, 2022).

2.3.3 Reduce the Risk of Injuries

RFID technology on safety vests has the potential to improve real-time human safety by lowering the risk of injury on construction sites. By incorporating RFID tags into safety vests, the system can monitor workers' proximity to heavy equipment, alerting both operators and workers to potential risks. This real-time monitoring and alert system can help prevent collisions by keeping workers aware of their surroundings and equipment operators informed of their locations, particularly in blind spots. As a result, this leads to a safer work environment with a lower risk of injuries due to improved situational awareness and timely communication of dangers (Chae & Yoshida, 2010).

2.3.4 Multi-tag support

An RFID reader can automatically read multiple tags in its read zone in a short period of time by employing an anti-collision algorithm. Using this scheme, a reader can uniquely identify a few to several tags per second, depending on the tag and the application. This feature enables a reader to read data from a collection of tagged objects, whether stationary or in motion (within the reader's limits), eliminating the need to read one tag at a time (Lahiri, 2006).

2.3.5 Perform Smart Tasks

An active tag's on-board electronics and power supply can be used for specialised tasks such as environmental monitoring. For example, detect motion (Lahiri, 2006). Table 1 shows the potential of RFID on safety vests for real-time human safety in construction sites.

Table 1 Potential of RFID on Safety Vest for Real-time Human Safety

No	Potential of RFID on Safety Vests for Real-time Human Safety	Author
1	Improved Incident Response	• Lim <i>et al</i> (2022)
2	Automated Hazard Alert	• Lim <i>et al</i> (2022)
3	Reduce the Risk of Injuries	• Chae & Yoshida (2010)
4	Multi-Tag Support	• Lahiri (2006)
5	Perform Smart Tasks	• Lahiri (2006)

2.4 Challenges of RFID Implementation on Safety Vests for Real-Time Human Safety

2.4.1 Low RFID Knowledge

The primary challenge in implementing RFID technology on safety vests for real-time human safety in construction sites is the Lack of understanding of RFID among workers. This gap in knowledge hinders the effective adoption and utilization of RFID for tracking and safety management, despite its potential to enhance on-site safety by providing real-time information and enabling quicker response to emergencies (Cecchi *et al.*, 2024).

2.4.2 Initial Costs

The initial costs of implementing RFID technology on safety vests for real-time human safety in construction sites can be significant. These costs include the purchase of RFID tags and readers, the development and deployment of the software systems required to integrate RFID data with existing safety management protocols, and personnel training on how to use the new technology. Furthermore, there may be costs associated with upgrading or adapting current safety vests to accommodate RFID tags, as well as ongoing maintenance and potential technology upgrades to ensure the system remains effective and compliant with the most recent safety standards. These financial considerations can be a significant barrier, especially for smaller construction companies with limited resources (Lim *et al.*, 2022).

2.4.3 Resistance to Change

Workers and management may be hesitant to implement new systems due to discomfort with technology, disruption of established routines, or scepticism about the benefits. Overcoming this Resistance requires effective communication about RFID's benefits, such as increased safety and accident prevention, as well as training programs to ensure a smooth transition and acceptance of the new safety protocols. Addressing privacy concerns and demonstrating the system's reliability can also help to reduce resistance and foster an innovative and safety-conscious culture (Chae & Yoshida, 2010).

2.4.4 RFID Accuracy

RFID technology, while useful for tracking and monitoring, can be subject to signal interference caused by construction materials and the site's dynamic environment, resulting in inconsistent detection ranges. The

amorphous detection range of RFID readers, combined with the movement of equipment and obstructions, can cause noise and data inaccuracies. These factors make it difficult to accurately estimate the personnel's working area and location, which is critical for avoiding heavy equipment collisions. As a result, ensuring the reliability and accuracy of RFID systems is critical for effective safety management in construction (Chae & Yoshida, 2010).

2.4.5 Lack of Training

Workers and management may not receive adequate training on how to use the RFID system effectively, resulting in underutilization or incorrect usage. Because of this knowledge gap, the technology's potential to improve safety and efficiency may not be fully realized. Furthermore, without proper training, there is a risk of data misinterpretation, which could jeopardize safety measures and slow emergency response times. As a result, comprehensive training programs are required to ensure that all personnel are skilled at operating RFID systems and can use them to improve overall site safety (Lim *et al.*, 2022). Table 2 depicts the challenges of RFID implementation on safety vests for real-time human safety in construction sites.

Table 2 Challenges of RFID Implementation on Safety Vest for Real-time Human Safety in Construction Site

No	Challenges of RFID Implementation on Safety Vests for Real-time Human Safety in Construction Sites	Author
1	Low RFID Knowledge	• Cecchi <i>et al.</i> (2024)
2	Initial Cost	• Lim <i>et al.</i> (2022)
3	Resistance to Change	• Chae & Yoshida (2020)
4	RFID Accuracy	• Chae & Yoshida (2020)
5	Lack of Training	• Lim <i>et al.</i> (2022)

2.5 Strategies to Promote RFID on Safety Vests for Real-Time Human Safety

2.5.1 Education and Training Programs

Education and training programs play an important role in promoting RFID technology on safety vests for real-time human safety on construction sites by raising awareness and fostering understanding among stakeholders (Lee & Kim, 2017). These programs equip construction industry professionals with the knowledge and skills required to effectively use RFID-enabled safety vests, allowing them to better leverage technology for improved safety outcomes. Workers are educated and trained in the functionalities of RFID technology, such as real-time location tracking and hazard detection capabilities, as well as best practices for incorporating RFID-enabled safety vests into their daily workflows. Education and training programs help workers adopt and integrate RFID technology into safety protocols on construction sites, ultimately contributing to improved safety and risk mitigation efforts (Han *et al.*, 2018).

2.5.2 Customer Engagement and Support

Effective customer engagement and support play an important part in promoting the use of RFID technology in safety vests for real-time human safety monitoring on construction sites. By actively involving customers through interactive communication, firms can educate them about the benefits of RFID vests, such as enhanced worker safety and accident prevention. Supportive services, including training and real-time assistance, ensure that customers understand the technology's application and its integration into safety protocols. This engagement fosters trust and encourages adoption by making customers feel valued and confident in the product's ability to improve safety standards and operational efficiency on construction sites (Barger *et al.*, 2016).

2.5.3 Partnership and Collaborations

Partnerships and collaborations are critical in advancing RFID technology integration into safety vests for real-time human safety monitoring. Companies can collaborate to pool resources, share expertise, and drive

innovation, resulting in more advanced, dependable, and cost-effective RFID solutions. Collaborative efforts can also help to standardize and widely adopt safety protocols across the industry, ensuring that safety vests with RFID technology become a common practice for proactive accident prevention on construction sites. Such collaborations can result in improved data collection and analysis, better risk management, and, ultimately, a significant reduction in construction accidents and injuries (Yang *et al.*, 2024).

2.5.4 Leadership and Industry Advocacy

Thought leaders can increase awareness of the benefits and applications of RFID technology by sharing insights, research findings, and best practices in articles, white papers, and presentations at industry conferences. This dissemination of knowledge helps to educate industry stakeholders about how RFID-enabled safety vests can enhance worker safety by providing real-time location tracking, monitoring worker movements, and improving response times to hazardous situations (Hallowell & Gambatese, 2009). Moreover, industry advocacy involves active participation in industry groups, standards committees, and policy-making bodies to drive the adoption of RFID technology in safety protocols. By advocating for the inclusion of RFID technology in safety regulations and standards, advocates can influence policy and create a more favourable environment for the deployment of RFID solutions. This can result in increased investment in RFID technology, broader acceptance among construction firms, and, ultimately, greater adoption of RFID-enabled safety vests. Successful case studies and pilot projects demonstrated through these channels help to reinforce the technology's credibility and practical benefits (Teizer *et al.*, 2010).

2.5.5 Informative Content

Informative content can help raise awareness about the innovative use of RFID in safety vests. Articles, white papers, and blog posts that explain how RFID technology works, its benefits, and its applications in construction safety can help stakeholders learn. This awareness is critical in generating interest and consideration from construction companies, safety officers, and regulatory bodies (Roberts, 2006). Informative content, such as case studies and success stories, can demonstrate the practical benefits of RFID safety vests. These stories demonstrate how real-time tracking improves safety by sending immediate alerts when workers enter hazardous zones or accidents occur, allowing for faster emergency responses (Smith *et al.*, 2003). Table 3 shows the strategies to promote RFID on safety vests for real-time human safety in construction sites.

Table 3 Strategies to Promote RFID on Safety Vest for Real-time Human Safety Vest for Real-time Human Safety

No	Strategies to Promote RFID on Safety Vest for Real-time Human Safety Vest for Real-time Human Safety in Construction Site	Author
1	Education and Training Programs	<ul style="list-style-type: none"> • Lee & Kim (2017) • Han <i>et al.</i> (2018)
2	Customer Engagement and Support	<ul style="list-style-type: none"> • Barger <i>et al.</i> (2016)
3	Partnership and Collaborations	<ul style="list-style-type: none"> • Yang <i>et al.</i> (2012)
4	Thought Leadership and Industry Advocacy	<ul style="list-style-type: none"> • Hallowell & Gambatese (2009) • Teizer <i>et al.</i> (2010)
5	Informative Content	<ul style="list-style-type: none"> • Roberts (2006) • Smith <i>et al.</i> (2003)

3. Research Methodology

3.1 Research Design

In the context of the study on RFID implementation in safety vests for construction sites, qualitative research methods are used to gain insights into the potential, challenges, and strategies for real-time human safety monitoring. These methods enable researchers to delve deeply into the perceptions, attitudes, and experiences of government agency, technical executive, consultants, and site safety supervisor in Malaysia which is involved in the use of RFID D technology for safety. Semi-structured interviews with government agency, technical executive, consultants, and site safety supervisor in Malaysia. Respondents were selected based on their extensive and comprehensive experience in utilizing RFID technology. These interviews allow us to gather detailed information about the contractors' perspectives on the feasibility and effectiveness of incorporating RFID technology into safety vests (Denzin & Lincoln, 2018). Additionally, this study outlines its research processes into five phases; Phase 1: Preliminary Study (identification of research background, problem statement, research questions and objectives, research scope and significance of research), Phase 2 (literature review), Phase 3: Data Collection (collection of primary and secondary data), Phase 4: Data Analysis (content analysis), and Phase 5: Conclusion and Recommendation.

3.2 Data Collection

3.2.1 Primary Data

In the context of the study on RFID implementation in safety vests for construction sites, primary data collection entails gathering firsthand information from respondents of this study, who consist of a technical executive, a founder, a business development manager, a government agency representative, and a site safety supervisor in Malaysia. Respondents were selected based on their extensive and comprehensive experience in utilizing RFID technology, using methods such as semi-structured interviews. These interviews are intended to elicit insights, perspectives, and experiences related to the incorporation of RFID technology into safety vests for real-time human safety prevention on construction sites.

3.2.2 Secondary Data

Secondary data sources used in the study on RFID implementation in construction safety vests include books, online journal papers, internet articles, and research publications from platforms such as Google and Google Scholar. These resources provide useful background information, theoretical frameworks, and empirical findings about RFID technology, construction safety, and relevant industry practices. By reviewing existing literature, researchers can expand on previous studies, theories, and findings, furthering knowledge and contributing to academic discourse. Secondary data sources will be gathered through literature reviews relevant to the study.

3.3 Research Population and Sampling

The study on RFID implementation in safety vests for real-time human safety on construction sites includes a wide range of stakeholders involved in construction site safety protocols and RFID technology integration. This includes the experts in RFID and safety in Malaysia. Purposeful sampling is used to select participants who have relevant expertise, experience, and perspectives aligned with the research objectives.

3.4 Research Instrument

In the context of the study on RFID implementation in safety vests for construction sites, semi-structured interviews are conducted with key stakeholders such as government agencies, technical executives, consultants, and site safety supervisors in Malaysia. It entails testing research procedures, instruments, or methodologies on a smaller sample size in order to identify and address potential issues or challenges before beginning the main study. In the context of the study on RFID implementation in safety vests for construction sites, a pilot test could include administering the semi-structured interview guide to a small group of participants to assess its clarity, relevance, and effectiveness in eliciting meaningful answers (Creswell, 2013). The pilot study will be conducted and tested with UTHM Lecturers from the Faculty of Technology Management and Business (FPTP).

3.5 Data Analysis

For this study, qualitative content analysis is the preferred method due to its suitability for qualitative sampling approaches. Once all the required data has been collected, the data analysis process can begin. Subsequently, meticulous care is taken to ensure data saturation while eliminating any unnecessary or undesirable information. It is best to compile the data in its raw, intricate form before attempting to identify underlying patterns. Effective analysis requires asking relevant questions to determine the primary focus of the analysis (Jones, 2018).

Researchers can draw conclusions about the texts' content, authorship, intended audience, and the socio-cultural context in which they were created.

4. Results and Discussion

4.1 Results

The purpose of this study is to assess the viability of integrating RFID technology into safety vests for construction sites. To assess how effective it is in preventing human safety in real time, it seeks to identify the requirements and difficulties related to its implementation. The study aims to provide precise guidelines and recommendations for the successful implementation of RFID-enabled safety vests by examining their viability and potential obstacles. This could result in a notable enhancement of worker safety on construction sites. Table 4 shows the results of respondent's background involved in this study.

Table 4 Respondent's Background

Respondents (R)	Company	Position	Years of experience	Scope of work	Years of Experience in using RFID
R1	RFID supplier	Technical Executive	15 years	<ul style="list-style-type: none"> Repair and installation Customize RFID hardware 	15 Years
R2	Technical Consulting Company	Founder	15 years	<ul style="list-style-type: none"> RFID design and services 	15 Years
R3	IoT solutions provider & RFID	Business Development Manager	5 years	<ul style="list-style-type: none"> RFID Specialist Provide RFID implementation solution and consultation to local and overseas company 	5 years
R4	Government Agency	Deputy Director	28 years	<ul style="list-style-type: none"> Safety and health 	2 Years
R5	Water and wastewater treatment solutions	Site Safety Supervisor cum AGTES	3 years	<ul style="list-style-type: none"> Civil structure, mechanical and electrical 	1 year

4.1.1 Potential of RFID Implementation on Safety Vest for Real-Time Human Safety

RFID implementation in safety vests enhances real-time construction site safety, as highlighted by respondents, through features like automated hazard alerts, real-time tracking, and multi-tag support. Respondents noted that RFID tags track worker locations, send alerts for unauthorized access or proximity to hazards, and can even trigger equipment shutdowns to prevent accidents. In emergencies, RFID aids evacuation by identifying workers' locations and streamlining rescue efforts. The system efficiently processes multiple tags simultaneously, even in crowded environments, while active tags with sensors monitor conditions like toxic gas or extreme temperatures, ensuring prompt alerts for unsafe situations (R1, R2, R3, R4, & R5).

4.1.2 Challenges of RFID Implementation on Safety Vest for Real-Time Human Safety

The challenges of deploying RFID on safety vests for real-time safety in construction, as highlighted by respondents, include low RFID knowledge, high initial costs, resistance to change, RFID accuracy issues, and lack of training. Workers may resist wearing RFID-tagged vests due to concerns about constant monitoring (R1, R4, R5), though R3 argues that workers don't need to understand RFID since it operates automatically. High costs, including active RFID systems, infrastructure, and ongoing maintenance, are major hurdles (R1, R3, R4, R5). Resistance to technology and discomfort may also hinder adoption (R5). RFID accuracy depends on proper setup (R1, R3, R4), and a lack of training or misunderstanding about the system's purpose can lead to misinterpretation and errors (R2, R3).

4.1.3 Strategies to Promote RFID Implementation on Safety Vest

The strategies to promote RFID-enabled safety vests for real-time construction site safety, as emphasized by respondents, include education and training programs, customer engagement and support, partnerships and collaborations, leadership advocacy, and informative content. All respondents highlighted the importance of educating stakeholders about RFID's benefits through real-time demonstrations on-site (R1, R2, R3, R4, R5). Customer engagement with ongoing feedback and support ensures smoother implementation (R1, R2, R4). Leadership advocacy through sharing success stories and best practices drives industry-wide adoption (R1, R4). Informative content, such as articles and white papers, educates stakeholders and raises awareness about RFID's advantages (R2, R5).

4.2 Discussion

4.2.1 Knowledge of RFID

Respondents stated they had not yet applied RFID technology in safety on site. Nevertheless, they have been experienced and well known in the use of RFID. The respondents demonstrated a high level of knowledge and understanding of RFID technology, largely attributed to their extensive experience in using it. For example, both R1 and R2 have 15 years of hands-on experience with RFID, showcasing their deep familiarity and expertise in this field. Table 5 shows a summary of the knowledge of RFID among respondents.

Table 5 Summary on the Knowledge of RFID among Respondents

Statement	R1	R2	R3	R4	R5
Knowledge of RFID					
Exposure to RFID	✓	✓	✓	✓	✓

4.2.2 Potential of RFID Implementation on Safety Vest for Real-Time Human Safety

As shown in Table 6 below, the two things that all respondents agreed on the most were improved incident response and smart task performance. This is because RFID tags can locate employees anywhere, they are in the vicinity of an RFID reader's radar. This is also because of the ability of active RFID tags with motion detection capabilities in areas where unauthorized access or intrusions need to be monitored (Lahiri, 2006). This aids in identifying when an employee enters a dangerous area, like a confined space zone, or one that is only accessible by authorized individuals. Hence, incorporating RFID into safety vests is a proactive approach to improving safety management in the construction industry (Lim *et al.*, 2022). Table 6 depicts the summary on the potential of RFID implementation on safety vest for real-time human safety in construction sites.

Table 6 Summary on the Potential of RFID Implementation on Safety Vest

Statements	R1	R2	R3	R4	R5
• Improved incident response	✓	✓	✓	✓	✓

• Automated hazard alert		✓	✓	✓	✓
• Reduce the risk of injuries		✓	✓	✓	✓
• Multi- tag support	✓	✓	✓	✓	✓
• Perform smart task	✓	✓	✓	✓	✓

4.2.3 Challenges of RFID Implementation on Safety Vest for Real-Time Human Safety

Low RFID expertise, in my opinion, was the primary challenge since it can result in other difficulties. Despite RFID's potential to improve on-site safety by enabling faster reaction to emergencies and delivering real-time information, this knowledge gap prevents its successful acceptance and utilization in safety management and tracking (Cecchi *et al.*, 2024). Table 7 shows the challenges of deploying RFID on safety vests for real-time human safety prevention in construction sites.

Table 7 Challenges of RFID Implementation on Safety Vest for Real-Time Human Safety

Statements	R1	R2	R3	R4	R5
• Low RFID knowledge	✓	✓		✓	✓
• Initial cost	✓	✓	✓	✓	✓
• Resistance to change	✓	✓	✓	✓	✓
• RFID accuracy	✓	✓	✓	✓	✓
• Lack of training	✓	✓	✓	✓	✓

4.2.4 Strategies to Promote RFID Implementation on Safety Vest

The respondents emphasize the necessity of adopting a comprehensive approach that integrates education, training, and ongoing support for workers and industry leaders. By increasing awareness and cultivating understanding among stakeholders, education and training programs are crucial in pushing RFID technology on safety vests for real-time human safety on construction sites (Lee & Kim, 2017). Table 8 shows the summary of strategies to promote RFID implementation on safety vests for real-time human safety.

Table 8 Strategies to Promote RFID Implementation on Safety Vest for Real-Time Human Safety

Statements	R1	R2	R3	R4	R5
• Education and training program	✓	✓	✓	✓	✓
• Customer engagement and support	✓	✓	✓	✓	✓

• Partnership and collaborations	✓	✓	✓	✓
• Thought leadership and industry advocacy	✓	✓	✓	✓
• Informative content	✓	✓	✓	✓

5. Conclusion

In conclusion, the research highlights the promising potential of RFID technology in enhancing real-time human safety on construction sites, particularly through its integration into safety vests. The ability to track worker locations and provide immediate alerts in emergency situations could significantly improve site safety and reduce risks. However, the adoption of RFID in Malaysia's construction industry faces challenges due to its limited use, industry awareness, and the time constraints of busy professionals. Despite these obstacles, the study provides valuable insights into the feasibility of RFID technology and its practical application. While the research successfully demonstrates the benefits of RFID for safety, it also identifies key areas for further exploration, including the combination of RFID with other safety technologies, cost-benefit analysis, and overcoming adoption barriers. Future research will be essential in refining implementation strategies, ensuring broader acceptance, and ultimately advancing safety practices in the construction industry. The findings suggest that with continued innovation and collaboration, RFID technology has the potential to revolutionize safety standards and practices in construction.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Shafeena Shahhin, Narimah Kasim; **data collection:** Shafeena Shahhin; **analysis and interpretation of results:** Shafeena Shahhin, Narimah Kasim; **draft manuscript preparation:** Shafeena Shahhin, Narimah Kasim. All authors reviewed the results and approved the final version of the manuscript.

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