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Authors Narimah Kasim, Sali Amirah Razali, Rozlin Zainal, Sharifah Meryam Shareh Musa, Hamidun Mohd Noh, Aawag Mohsen Alawag, Abdullah O. Baarimah, Chukwuka Ohueri and Mansir Dodo

Key Elements and Requirements of Industrial Revolution 4.0 Technology Adoption in Smart Emergency Detection for the Malaysian Construction Industry

Narimah Kasim[1,2*], Sali Amirah Razali[1], Rozlin Zainal[1,2], Sharifah Meryam Shareh Musa[1,2], Hamidun Mohd Noh[1,2], Aawag Mohsen Alawag[3], Abdullah O. Baarimah[4], Chukwuka Christian Ohueri[5], Mansir Dodo[6]

[1]Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, Malaysia

[2]Center of Project, Property, and Facilities Management Services, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, Malaysia

[3]Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, 32610, Malaysia

[4]Department of Civil and Environmental Engineering, College of Engineering, A'Sharqiyah University, 400 Ibra, Oman

[5]School of Housing, Building and Planning, Universiti Sains Malaysia, Pulau Pinang, 11800, Malaysia

[6]Department of Building, Ahmad Bello University, PMB 1044 Samaru, Zaria, Kaduna State, Nigeria

*Corresponding Author: narimah@uthm.edu.my

Abstract:

Property loss and operation downtime in a small event can be mitigated by necessitating early detection systems. These systems function as emergency responders equipped with the capacity to notify the current situation information at the construction site. Therefore, this study analysed the key elements required to successfully adopt Industrial Revolution (IR) 4.0 technology in smart emergency detection for safety management. The analysis also established various smart emergency detection requirements for safety management based on IR 4.0 technology. A total of 215 G7 Malaysian contractors were initially sought as respondents for this study. The data was obtained using a survey method employing descriptive statistics (frequency, percentage, and mean score). This process identified the ranking contribution between the key elements and requirements of smart emergency detection for safety management based on an IBM Statistical Package for Social Sciences (SPSS) software version 25. A total of 10 key elements were then ranked in this study: (i) components, (ii) cost, (iii) related work, (iv) strength, (v) challenges, (vi) data collection, (vii) place, (viii) equipment, (ix) economy, and (x) training. Six requirements were also ranked: (i) increased agility, (ii) smart, self-monitoring, and control, (iii) better connectivity, (iv) sustainability, (v) consistent self-registration, and (vi) ease of use. Consequently, a significant contribution was observed from the key elements and requirements involving the successful adoption of IR 4.0 technology in smart emergency detection for safety management. This outcome provided a holistic and integrated perspective for enhanced safety management performance and better decision-making choices by construction industry practitioners. Construction industry stakeholders could also present novel practices and policies for improved safety management performance containing IR 4.0 technology in developing countries using these findings.

Keywords: Construction industry; key elements; IR 4.0 technology; requirements; smart emergency detection

INTRODUCTION

Given the alarming and intricate nature of Malaysian workplace accidents, safety management in emergencies has generated significant concerns. The recent safety records in the construction industry have also raised substantial concerns for the government regarding these accidents (DOSH, 2020). These accidents can be directly ascribed to unsafe design and site practices. Hence, several industrial safety management-based studies have begun to explore Industrial Revolution (IR) 4.0 and intelligent technologies. These technologies are essential for disaster management and safety protocols within hazardous industries, such as the construction sector (Maskuriy *et al.*, 2019).

Certain studies have demonstrated the practical functionality of IR 4.0 technology in enhancing construction-related safety management practices (Azmy and Moh Zain, 2016). These studies have explored numerous smart technology types, including smart equipment, cities, and factories. Therefore, modern IR 4.0 technology based on advanced smart technology has emerged as a prevailing smart system trend extending beyond the Internet of Things (IoT) connection. This trend can generate Improved information exchange, data management, and communication processes by integrating IoT and Internet of Services for their cyber-physical system capabilities (Maskuriy *et al.*, 2019).

Various factors can affect the IR 4.0 technology adoption for construction safety performances, such as robust cybersecurity measures and emergent technologies [augmented reality (AR), virtual reality (VR), artificial intelligence (AI), big data analytics, and simulation] (Azmy and Moh Zain, 2016). Considering that IR 4.0 technology can monitor, predict, and ascertain alert necessity, users are offered an early warning to react (Costa *et al.*, 2020a; Jeelani *et al.*, 2021). Nevertheless, several challenges in widely disseminating actionable detection and warnings are highlighted in the construction sector. These constraints indicate that IR 4.0 technology should be adopted to activate a smart mechanism for on-site safety management.

The success rate of the transition to more intelligent systems is directly correlated with IR 4.0 technology. Among all the sectors using IR 4.0 technology, the construction industry can benefit from this transformation (Alaloul *et al.*, 2020). This observation suggests investigating the correlation between key elements with requirements and IR 4.0 technology for smart emergency detection in construction site safety. Significant progress has also been made in technology and safety regulations. Nonetheless, the construction sector still experiences formidable challenges regarding the persistent occurrence and escalation of on-site accidents.

The diverse and dynamic surroundings of construction sites present the interaction of several trades and activities. This process poses unique safety management challenges. Numerous studies have revealed that human error is a significant cause of fatal occupational accidents, which is often exacerbated by the inherently risky conditions of these workplaces (Lehtola *et al*., 2008; Fugas *et al*., 2012). This limitation highlights the urgent need for innovative solutions to address human and systemic factors.

In the year 2019, the Department of Health and Safety revealed that fatal accidents and deaths occurred at 2.20 per 100,000 workers in the Malaysian construction industry. The report denoted that a high rate necessitated the development of creative solutions. Hence, improved safety management on the construction site should be achieved by clearly identifying the key elements and requirements for smart emergency detection (Ahmed, 2019). These detection systems should effectively be enhanced using IR 4.0 technology for two primary objectives: (i) bridging the existing research gap for smart emergency detection and (ii) significantly contributing to enhanced safety management practices in the construction industry.

This study addressed the current research gap in smart emergency detection and significantly improved safety management procedures in the construction sector. Given the challenges, this study carefully identified and explained the key elements and requirements for smart emergency detection systems supported using IR 4.0 technology. This study also possessed a capacity to transform the construction industry in developing countries by introducing innovative, data-driven, and connected solutions for identifying and addressing emergency detection and response. The latest technological advancements with practical safety applications could enable essential knowledge dissemination for policymakers, industry leaders, and safety professionals to make informed decisions and strategies.

LITERATURE REVIEW

Smart Emergency Detection in Safety Management

An emergency system that can promptly notify the community of the potential occurrence of unforeseen accidents and natural disasters necessitates IR 4.0 technology adoption. Several nations such as Germany, the United States, the United Kingdom, China, Korea, and Japan have initiated their IR 4.0 conversion, with certain countries already in the advanced execution phases. One notable example involves a Japanese mobile alert system integrated with advanced technology. The Japan Meteorological Agency (JMA) has developed this system to provide early warnings before an earthquake occurs (Osamu, 2004).

Previous studies have employed Global Positioning System (GPS) and Automated Meteorological Data Acquisition System (AMeDAS) data (Nishio and Mori, 2012). These studies forecast earthquakes and tsunamis to notify the local Japanese population of potential hazards. Nevertheless, the IR 4.0 technology selection process must be determined to improve the detection of potentially hazardous events. This requirement implies that IR 4.0 technology in emergency detection systems is of utmost importance to enhance safety management within the construction industry.

Recent advancements in IR 4.0 technology still require further assessments of recognition, autonomous sensing, intelligent interconnecting, learning analysis, and decision-making capabilities in a smart system (Zhong *et al*., 2017). Therefore, various key elements necessitate identification to realise the concepts of Industry 4.0 and SMART systems (smart equipment, cities, and factories). Johnsen (2018) reported that the key elements in evaluating risks were determining the scope and prioritisation of systems. The study denoted that these key elements were highly relevant when addressing applications of the research. This process also involved the necessary instruments needed to manage a system efficiently.

Imkamp *et al*. (2016) revealed that the cyber-physical production system and complex production processes needed to integrate sensor and measurement technologies. The study explained that resolving hazards and establishing future smart emergency detection systems required optimal IR 4.0 technology to determine the design and operation. Traditionally, the CIDB Strategic Plan 2015–2021 mentioned three primary elements (economy, equipment, and component) for adapting IR 4.0 technology in the construction industry Construction 4.0 (CIDB, 2020). Nonetheless, key elements and requirements remain significant in smart emergency detection systems based on IR 4.0 technology.

Key Elements of Smart Emergency Detection

The key elements are essential to establishing the scope and prioritisation of systems in smart emergency detection. Previous studies primarily focused on several parameters, such as equipment (KE), components (KC), related work (KRW), cost (KCO), economy (KEC), strength (KS), challenges (KCH), data collection (KDC), training (KT), and place (KP). These studies demonstrated that KRW was frequently addressed, which was significant for identifying the real-time detection of potential hazards (falls, unsafe equipment, and machinery).

Previous studies demonstrated the significance of KC after KRW. The functional suitability of technological applications also influenced the selection of KE. Another significant barrier to the adoption of IR 4.0 technology by construction companies was KCO due to the low profit margins. This constraint led researchers to address this cost issue using IR 4.0 technology, owing to the advantages and necessity of smart technology in the construction industry. Although various key elements (KT, KEC, KS, KCH, KDC, and KP) were discussed, they appeared to be of low interest among the academic researchers. Table 1 presents a summary of the key elements derived from previous studies.

Table 1. Summary of the key elements in smart emergency detection for safety management

Key element	Source	Number of articles
Equipment (KE)	Cheng and Teizer (2013); Han and Lee (2013); Zhou *et al.* (2013); Wetzel and Thabet (2015); Jee Woong *et al.* (2017); Chen *et al.* (2020); Jiang *et al.* (2021); Tang *et al.* (2021); Guo *et al.* (2023)	9

Components (KC)	Cheng and Teizer (2013); Zhou *et al.* (2013); Wang *et al.* (2014); Wetzel and Thabet (2015); Golabchi *et al.* (2018); Asadzadeh *et al.* (2020); Lee *et al.* (2020); Nath *et al.* (2020); Tang *et al.* (2020); Yang *et al.* (2020); Jiang *et al.* (2021)	11
Related Work (KRW)	Cheng and Teizer (2013); Guo *et al.* (2013); Han and Lee (2013); Wang *et al.* (2014); Jee Woong *et al.* (2017); Golabchi *et al.* (2018); Rossi *et al.* (2019); Baker *et al.* (2020); Qijun *et al.* (2020); Jeelani *et al.* (2021); Lee *et al.* (2020); Liu *et al.* (2018); Park and Kim (2013)	13
Cost (KCO)	Wang *et al.* (2014); Edirisinghe (2019); Rossi *et al.* (2019); Baker *et al.* (2020); Chen *et al.* (2020); Getuli *et al.* (2020); Yang *et al.* (2020); Tang *et al.* (2021)	8
Economy (KEC)	Zhou *et al.* (2013); Edirisinghe (2019); Tang *et al.* (2020); Tang *et al.* (2021); Zhao *et al.* (2021)	5
Strength (KS)	Edirisinghe (2019); Nath *et al.* (2020); Qijun *et al.* (2020); Yang *et al.* (2020); Zhao *et al.* (2021)	5
Challenges (KCH)	Asadzadeh *et al.* (2020); Yang *et al.* (2020); Tang *et al.* (2021); Zhao *et al.* (2021)	4
Data Collection (KDC)	Cheng and Teizer (2013); Han and Lee (2013); Liu *et al.* (2018); Getuli *et al.* (2020)	4
Training (KT)	Guo *et al.* (2013); Park and Kim (2013); Wetzel and Thabet (2015); Chen *et al.* (2020); Tang *et al.* (2020); Jiang *et al.* (2021)	6
Place (KP)	Jeelani *et al.* (2021)	1

Requirements of Smart Emergency Detection

Table 2 tabulates the smart emergency detection requirements of IR 4.0 technology for safety management. Most studies noted that systems needed the capacity for smart self-monitoring in real-time and emergency detection control (RSS). An increased capability and guideline for efficiently configuring IR 4.0 technologies could also be achieved using increased agility (RA). This process allowed the company to manage external uncertainty effectively. Similarly, better connectivity (RC) was another significant requirement for smart technology.

Table 2. Summary of smart emergency detection requirements for safety management

Requirement	**Source**	**Number of articles**
Smart, Self-Monitoring, and Control (RSS)	Cheng and Teizer (2013); Nagy *et al.* (2018); Baker *et al.* (2020); Shahrour *et al.* (2020); Nath *et al.* (2020); Jeelani *et al.* (2021); Su *et al.* (2021); Saini *et al.* (2022); Xu *et al.* (2022)	9
Increased Agility (RA)	Chen *et al.* (2020); Su *et al.* (2021); Mrugalska and Ahmed (2021); Saini *et al.* (2022)	4
Better Connectivity (RC)	Baker *et al.* (2020); Yang *et al.* (2020); Zhao *et al.* (2021); Saini *et al.* (2022)	4
Sustainability (RS)	Malagnino *et al.* (2021); Saini *et al.* (2022); Xu *et al.* (2022)	3
Ease of Use (RE)	Zhou *et al.* (2021)	1
Consistent Self-Registration (RCS)	Chen *et al.* (2020)	1

Joensuu *et al.* (2020) stated that attaining sustainability (RS) for the construction industry was highly complex due to the unique characteristics of the sector. Costa *et al.* (2020) defined RS to encompass long-term stability, energy-saving construction technology, and encouragement and stimulation of eco-friendliness. In contrast, the literature analysis exhibited that two requirements were rarely reported: (i) ease of use (RE) and (ii) consistent self-registration (RCS). Generally, user requirements are frequently more readable and understandable. Concurrently, a clearer understanding of the functioning of a system is provided. These observations indicated that the RE of IR 4.0 technology was neglected.

The rarely reported RCS emerged as a novel approach to mitigate health and safety risks in construction projects. One example involved facial recognition systems, which enabled efficient worksite monitoring to enhance safety and security measures. Nevertheless, this technique was still underdeveloped for integration into technologies within the construction sector. Thus, smart emergency detection must consider this requirement to ensure safety at construction sites.

Key Elements and Requirements of IR 4.0 Adoption for Smart Emergency Detection

Even though previous studies proposed several IR 4.0 technological adoptions within safety management systems, the selection process involving key elements and requirements for emergency detection was relatively disregarded. Typically, IR 4.0 technology adoption significantly correlates to technology adoption tools, offering numerous advantages (Baker *et al.*, 2020; Tang *et al.*, 2020; Tang *et al.*, 2021). The

Malaysian government has also acknowledged the importance of IR 4.0 in the national agenda in a recent budget session (Idris, 2019).

The key elements and requirements for smart emergency detection in safety management remain critical in addressing the existing gap in previous studies. This process can aid in selecting relevant technology and encourage top management to allocate more budgetary resources. Consequently, these allocations can effectively persuade stakeholders to use IR 4.0 technology in safety management. A thorough literature analysis in this study also demonstrated insufficient IR 4.0-related studies concerning the key elements and requirements for smart emergency detection in safety management.

Numerous factors in the construction sector can influence safety management and serve as the root cause of the issues. Therefore, adopting IR 4.0 technology can improve operational efficiency, optimal management, and safety (Park *et al*., 2017; Jiang *et al*., 2021). Previous studies also reported that certain IR 4.0 technologies could minimise accidents and hazards. These studies presented five primary IR 4.0 technologies that were immensely beneficial in the emergency detection system: (i) VR, (ii) IoT, (iii) cloud computing, (iv) AI, and (v) big data (Zhao *et al*., 2021; Sharma *et al*., 2020). Nonetheless, the correlations between key elements with requirements and IR 4.0 adoption must be analysed to obtain a comprehensive understanding.

Currently, researchers have requested recommendations due to inadequate IR 4.0-related studies. These suggestions are vital in narrowing down the selection of systematic technology for emergency detection in smart device systems within construction safety measures. Hence, the contractor or construction player can comprehend the key elements and requirements of IR 4.0 technology adoption for smart emergency detection in safety management. Figure 1 depicts the research conceptual framework involving the key elements and requirements of IR4.0 technology adoption for smart emergency detection in enhancing safety performance.

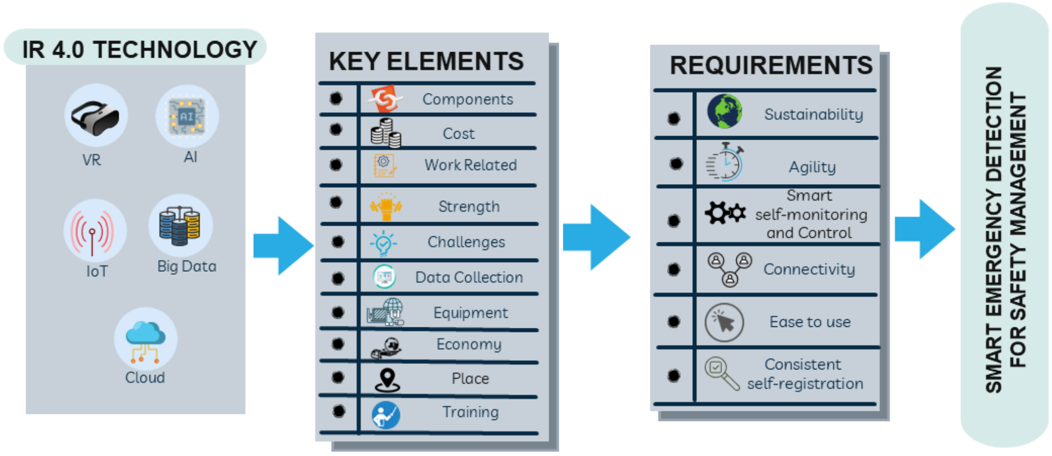

Figure 1. The research conceptual framework used in this study

METHODOLOGY

Data Collection

A comprehensive literature review involved the design, execution, and secondary data source documentation processes. The data sources included books, journal articles, conference proceedings, reports, legal rules and regulations, Master's dissertations, and Doctoral theses. Kraus *et al*. (2020) asserted that systematic reviews represented the first stage in more extensive research efforts. The study denoted that this stage could present a comprehensive overview of the existing literature and incorporate it into a well-structured synthesis. Thus, the existing literature observed in this study contained various key topics on smart emergency detection concerning IR 4.0 technology adoption for safety management.

The key elements and requirements regarding smart emergency detection using IR 4.0 technology were recorded through a literature analysis. Kabir (2016) stipulated that the data gathering process commenced with primary data collection. Therefore, the primary data collection method used in this study was quantitative to determine the key elements and requirements for IR 4.0 technology of smart emergency detection in construction safety management. Ahmad *et al*. (2019) documented that a quantitative approach could establish a causal relationship between two variables through mathematical, computational, and statistical methods. Consequently, these techniques could enable precise measurement.

Empirical data are commonly classified, ranked, or measured in precise units of measurement to facilitate analysis and evaluation. This statement was supported by Cooper and Schindler (2000), which denoted that this process was unlikely to impact research results. Thus, this study converted the collected respondent feedback into coded, categorised, and quantified data suitable for statistical analysis. The quantitative methodology in this study was also deemed appropriate based on these justifications.

The questionnaire distribution process during data collection was substantially correlated with respondent selection and study area. Each stage of the questionnaire development in this study was also associated with questionnaire design and strategies. The respondents' feedback was then collected using research questionnaires based on a five-point Likert scale, ranging from "strongly disagree" to "strongly agree". This five-point Likert scale was chosen due to its alignment with the research objectives of this study, which was to comprehend the respondents' opinions and perceptions of the topic (Joshi *et al*., 2015).

Section A of the questionnaires focused on respondent demographics. Section B examined the key elements of adopting IR 4.0 technology in smart emergency detection for safety management. Section C explored the requirements of smart emergency detection using IR 4.0 technology for safety management. The segmented questionnaires were used to systematically gather information on the research objectives and comprehensively understand respondents' perspectives.

Social science experts usually recommend a pilot test to examine various topics such as validity, reliability, instrument development, and early-scale development (Johanson and Brooks, 2010; Lucko and Rojas, 2010; Neuman, 2011; Joshi *et al*., 2015). This test can evaluate if the research proposition of the questionnaire is sufficient for the responder to understand the results (Johanson and Brooks, 2010). Simultaneously, any potentially misleading questions impacting the main research project are removed. This test also often yields ideas, techniques, and suggestions overlooked before the primary survey. The process involves analysing the questionnaire to identify the aspects that could be improved, format, understanding of the questions among respondents, and difficulty level.

Majid (2018) proposed that the population was the specific individuals in a study requiring investigation. This population was determined using a random sampling system, whereas the research was conducted on various individuals who met the specific criteria of the study. Therefore, the sample size in this study was identified using Slovin's formula, which was calculated with a standard error of 5% (0.05) (Slovin, 1960). The study population consisted of G7 contractors directly involved in the construction sector across Peninsular Malaysia.

CIDB (2018) disclosed that approximately 4,828 registered G7 contractors in Peninsular Malaysia were present. The respondents included in the unit analysis of this survey were also construction industry practitioners who collaborated with a G7 contractor responsible for safety management and directly involved in a construction project. These practitioners included project managers, site engineers, supervisors, and health and safety officers. Furthermore, the G7 contractors in this study employed IR 4.0 technology, which was a crucial component of this study.

The equal probability of inclusion for every individual in the selected population determines the randomness of a sample. Depending on the methodology, this sampling process can infer a population or generalise an existing theory (Majid, 2018). An estimated sample size of 370 was then derived in this study using Slovin's formula from a population of 4828. The population of active G7 contractors registered with CIDB was also 4828, indicating that the sample size of 370 was adequately representative. This methodology was employed based on a minimum of 100 valid responses (Saunders *et al.*, 2009). Meanwhile, the questionnaire was distributed to 370 G7 contractors through email, WhatsApp, Telegram (Google Form survey), and in-person meetings.

Data Analysis

This study employed descriptive analysis to examine the ranks of key elements and requirements for smart emergency detection in enhancing safety performance. Previous studies revealed that this ranking was contingent upon the mean score of each item. This descriptive analysis was then conducted using the Statistical Package for the Social Sciences (SPSS) version 25. Considering that data normality was a fundamental assumption in parametric testing, an accurate assessment of data normality was essential for several statistical tests (Mishra *et al.*, 2019). Costello and Osborne (1994) and Field (2009) argued that large samples should be tested for statistical significance. This process was crucial in evaluating the normal distribution by testing the statistical significance of skewness and kurtosis.

The coefficient alpha (or Cronbach's alpha, α) generally quantifies the reliability of a test by analysing data from a single administration. Similarly, the internal consistency coefficient is mainly applied in organisational research (Cho and Kim, 2015). This α value should adhere to the core assumptions of the fundamental method as a reliability index. In addition to evaluating test homogeneity or one-dimensionality, this α value also considers the impact of test length on its reliability (Hoekstra *et al.*, 2019). Therefore, increasing the length of a test enhances its reliability, which is contingent upon the test being homogeneous.

A high a value above 0.90 typically suggests redundancy and implies that the test length should be minimised (Hoekstra *et al*., 2019). Taber (2018) revealed that the widely accepted social science cut-off point for a set of items to be classified as a scale was an *a* value of 0.70 or above. Nevertheless, certain studies used *a* value of 0.75 or 0.80, while others adopted a more lenient criterion of 0.60 (Konting *et al*., 2009).

RESULTS AND DISCUSSION

Preliminary Data Analysis

A total of 370 questionnaires were distributed to the representatives of the chosen G7 contractors, of which 221 questionnaires were returned after six months. This process resulted in a 60% response rate communicated by email, WhatsApp, and face-to-face interviews. Fincham (2008) reported that the multimode approach yielded response rates of nearly 60% in a completed trial, surpassing the response rates achieved by the single method. Norizam *et al*. (2015) documented that the survey response rates in the construction sector were frequently between 20% and 30%. Hair (2010) published that data screening and examination were advantageous in detecting missing values, outliers, multicollinearity, and response bias.

This study identified six out of 221 questionnaires as multivariate outliers. Several suggestions for addressing outliers involved retaining or removing the outliers. Thus, this study removed the six outliers after performing a multivariate outlier analysis. The remaining 215 questionnaires were within the optimal sample size and sufficient for further assessment.

Normality and Reliability

The normality of a distribution was evaluated using a Kolmogorov-Smirnov test. Meanwhile, the skewness ratio to the standard error of skewness was obtained using the Skewness and Kurtosis test. This value should be between -1.96 and +1.96, indicating a normal data distribution. Table 3 lists the normality assumptions for all constructs derived from these two tests. The Kolmogorov-Smirnov test suggested that each variable possessed statistically significant values of 0.00. This outcome implied that the data did not follow a normal distribution. Subsequently, the Skewness and Kurtosis test demonstrated that the data did not follow a normal distribution, with skewness values ranging from -3.183 to -7.142.

Table 3. Summary of normality test results based on Kolmogorov-Smirnov and Skewness and Kurtosis tests

No.	**Construct**	**Skewness**			**Kurtosis**			**Kolmogorov-Smirnov**	
		Sta.	**Error**	**Z**	**Sta.**	**Error**	**Z**	**Sta.**	**Sig.**
1	Equipment (KE)	-.812	0.166	-3.305	.871	0.330	1.458	.141	.000

2	Place (KP)	-.846	0.166	-4.847	.762	0.330	1.971	.182	.000
3	Components (KC)	-.772	0.166	-4.934	.848	0.330	1.280	.153	.000
4	Cost (KCO)	-.484	0.166	-3.704	-.428	0.330	0.499	.121	.000
5	Related Work (KRW)	-.591	0.166	-3.546	.455	0.330	0.217	.142	.000
6	Economy (KEC)	-.514	0.166	-4.225	.035	0.330	1.846	.137	.000
7	Strength (KS)	-.562	0.166	-4.160	.176	0.330	1.157	.147	.000
8	Challenges (KCH)	-.401	0.166	-3.183	.006	0.330	0.221	.153	.000
9	Data Collection (KDC)	-1.235	0.166	-7.142	2.880	0.330	9.011	.187	.000
10	Training (KT)	-.988	0.166	-5.630	1.750	0.330	5.249	.147	.000
11	Smart, Self-monitoring, and Control (RSS)	-.557	0.166	-5.284	.570	0.330	4.109	.164	.000
12	Increased Agility (RA)	-1.007	0.166	-5.316	1.117	0.330	4.245	.181	.000
13	Better Connectivity (RC)	-.677	0.166	-5.191	.458	0.330	3.545	.173	.000
14	Sustainability (RS)	-.664	0.166	-6.301	.511	0.330	5.711	.159	.000
15	Ease to Use (RE)	-.787	0.166	-4.654	.405	0.330	0.986	.197	.000
16	Consistent Self-Registration (RCS)	-.770	0.166	-4.595	.807	0.330	2.450	.206	.000

A general approach for assessing the reliability or internal consistency of a research instrument is analysing the *a* value. Hoekstra *et al.* (2019) recommended that each construct should contain the *a* analysis containing causes and effects (rather than for the entire scale). Table 4 summarises the reliability test for the actual survey of this study. Given that this study established a threshold acceptance *a* value of 0.71 and above, each construct exceeded the threshold value (between 0.715 and 0.841). Consequently, the observed ranges indicated that the items within these constructs exhibited acceptable internal consistency. The measured scale also revealed that all items demonstrated a satisfactory reliability level.

Table 4. Summary of the reliability test for each construct

No.	**Construct**	**Number of Items**	***a***
	Key Element		
1	Equipment (KE)	5	.715
2	Place (KP)	2	.805
3	Components (KC)	5	.841
4	Cost (KCO)	7	.803
5	Related Work (KRW)	4	.746
6	Economy (KEC)	4	.746
7	Strength (KS)	5	.814
8	Challenges (KCH)	4	.724
9	Data Collection (KDC)	4	.820
10	Training (KT)	4	.789
	Requirement		
1	Smart, Self-monitoring, and Control (RSS)	4	.716
2	Increased Agility (RA)	4	.828
3	Better Connectivity (RC)	3	.787
4	Sustainability (RS)	4	.802
5	Ease to Use (RE)	2	.768
6	Consistent Self-Registration (RCS)	2	.806

Demographic Analysis of Respondents

Table 5 presents the demographic profile for this study. Safety and health officers (22.8%) and site safety supervisors (21.4%) held the highest percentages of positions at the company. Meanwhile, project managers and site engineers comprise 20.9% and

20.5%, respectively. Other remaining positions (architect, residential engineering, and managing directors) were the least represented among the respondents (14.4%). Among the 215 respondents, the most significant proportion of respondents (32.1%) were employed in construction companies aged between 26 and 30. This age group was followed by those aged from 31 to 40 (29.3%), 22 to 25 (32.1%), 41 and above (17.7%), and 18 to 21 (0.5%). The outcomes suggested that respondents aged 26 to 30 were actively engaged and involved in research.

Table 5. Summary of the respondents' background

No.	**Item**	**Frequency (*n* = 215)**	**Percentage (%)**
1	**Company Position**		
	Project Manager	45	20.9
	Site Engineer	44	20.5
	Site Supervisor	46	21.4
	Health and Safety Officer	49	22.8
	Others	31	14.4
2	**Respondents' Age**		
	18–21	1	0.5
	22–25	44	20.5
	26–30	69	32.1
	31–40	63	29.3
	> 41	38	17.7
3	**Respondents' Working Experience**		
	1–5	66	30.7
	6–10	39	18.1
	11–15	57	26.5
	16–20	28	13.0
	> 20	25	11.6
4	**Respondents' Working Experience in Technology**		

	1–5	99	46.0
	6–10	66	30.7
	11–15	39	18.1
	16–20	7	3.3
	> 20	4	1.9
5	**Project Involvement Type**		
	Residential Housing Construction	98	16.8
	Institutional and Commercial Building Construction	114	19.6
	Specialised Industrial Construction	111	19.0
	Government Project	81	13.9
	Private Project	63	10.8
	Others	2	0.3
6	**Risk Type**		
	High	104	34.0
	Medium	157	51.3
	Low	45	14.7
7	**Number of Staff Involved at the Construction Site**		
	1–10	20	9.3
	11–50	55	25.6
	51–100	60	27.9
	101–250	43	20.0
	251–500	24	11.2
	> 500	13	6.0
8	**Respondents' Education**		
	Diploma	36	16.7
	Degree	159	74.0

Master	18	8.4
PhD	1	0.5
Others	1	0.5

The experience data encompassed expertise in the construction industry and technology experience. This observation indicated that respondents must possess first-hand knowledge of technology. The criterion was necessary to verify that the respondents possessed the minimum credentials to answer the questionnaires on smart emergency detection in obtaining the key elements and requirements. Consequently, most respondents (30.7 %) had 1 to 5 years of experience. This outcome was followed by 11 to 15 years (26.5%), 6 to 10 years (18.1%), 16 to 20 years (13%), and more than 20 years (11.6%).

The figures indicated that most respondents possessed construction experience ranging from 1 to 5 years. These results also signified that less than 50% of the respondents had 1 to 5 years of technological expertise. The specific proportions of respondents' experience in managing materials were 1 to 5 years (46%), 6 to 10 years (30.7%), 11 to 15 years (18.1%), 16 to 20 years (3.3%), and more than 20 years (1.9%). Upon examining these two experience facets, the percentage range was highly inconsistent. This finding suggested that a smaller percentage of respondents possessed prior industrial expertise, and a similar observation held for the percentage involving technological experience.

Most respondents (19.6%) were from institutional, commercial building, infrastructure, and heavy constructions. This outcome was followed by specialised industrial construction (19%), residential housing construction (16.8%), government projects (13.9%), and private projects (10.8%). The others (0.3%) were identified as the solar technology industry. Likewise, the composition of respondents involving risk type was separated into three groups: (i) moderate (50.3%), high (34.4%), and low (14.7%) risks. Most respondents' experiences with safety management projects in the construction industry involved medium-risk projects. This distinctive outcome was attributed to the two-facet situation. Nearly 50% of the respondents also disclosed that their involvement was influenced by the risk level of the specific construction project types during the face-to-face data collection process.

This study examined the educational levels of the respondents, with the most significant percentage of individuals possessing a bachelor's degree (74.0%). This finding was followed by a diploma (16.7%), Master's degree (8.4%), doctorate (0.5%), and others (0.5%).

Key Elements of Smart Emergency Detection

This study investigated the ranking of key elements of IR 4.0 technology in smart emergency detection using descriptive analysis. This ranking was established based on the mean score for each item factor (refer to Table 6). A score of 4 on the questionnaire generally indicates a 'relevant' rating classification. Consequently, three factors with mean scores of 4.4 in KT were observed: (i) evaluate effectiveness (KT3), (ii) transfer knowledge, skills, and abilities (KT2), and (iii) develop detailed content and instructional design (KT4). This outcome implied that the respondents identified the elements in IR 4.0 technology for smart emergency detection in safety management within the construction sector.

Table 6. Rank summary of the key elements for smart emergency detection in safety management

Code	Item	Mean	Rank	Overall rank
	Equipment (KE)			
KE2	Increase equipment visibility	4.3302	1	12
KE5	User ability of equipment	4.2884	2	20
KE4	Monitor equipment expenses to ensure profitability	4.2326	3	31
KE3	Cover equipment issues	4.2220	4	33
KE1	Proper equipment maintenance	4.2219	5	34
	Place (KP)			
KP2	Identification of the surrounding environment area	4.3767	1	7
KP1	Identification of technology installation area	4.2930	2	15
	Components (KC)			
KC2	Relevant hardware	4.2600	1	24
KC1	Relevant software	4.2488	2	25
KC6	Peripherals (input-output device)	4.2458	3	26
KC3	Infrastructure necessary for communications	4.2458	4	27
KC5	Future upgrades	4.2419	5	29
	Cost (KCO)			
KCO2	Long-term saving	4.4011	1	4
KCO3	Hardware	4.3860	2	5
KCO8	Cost-benefits of technology	4.2930	3	16
KCO7	External expertise contractor	4.2409	4	30

KCO4	Software	4.1781	5	41
KCO6	Training	4.1605	6	42
KCO5	Maintenance	4.1521	7	43
	Related Work (KRW)			
KRW2	Return on investment cost	4.2914	1	18
KRW1	System that applies in the emergency detection system	4.2702	2	23
KRW4	Current direction of technology	4.1944	3	38
KRW5	Future direction of technology	4.1830	4	40
	Economy (KEC)			
KEC4	Government/Organisational support	4.2937	1	14
KEC1	Economic impact on the construction industry	4.2837	2	21
KEC3	Positive economic growth	4.2442	3	28
KEC2	Employment growth	4.2023	4	36
	Strength (KS)			
KS1	Strong product image	4.3449	1	9
KS3	Robust financial performance	4.3447	2	10
KS4	Improved communication	4.2791	3	22
KS5	Easy access information	4.1988	4	37
KS2	Reliable of technology	4.1888	5	39
	Challenges (KCH)			
KCH5	Expertise/staff training	4.3349	1	11
KCH3	Security threats	4.2884	2	19
KCH4	Changes in the regulations	4.2140	3	35
KCH2	Patent Infringement	4.0930	4	44
	Data Collection (KDC)			
KDC3	Reliable in decision-making	4.3488	1	8

KDC4	Sharing the information	4.3209	2	13
KDC2	Data collection source	4.2930	3	17
KDC1	Effective system data collection identification	4.2279	4	32
	Training (KT)			
KT3	Evaluate effectiveness	4.4512	1	1
KT2	Transfer knowledge, skills, and abilities	4.4326	2	2
KT4	Develop detailed content and instructional design	4.4053	3	3
KT1	Develop education and training materials	4.3767	4	6

The key elements for KCH and KCO contained three factors: (i) patent infringement (KCH2), (ii) maintenance (KCO5), and (iii) training (KCO6). Each key element in this study was also arranged based on their ranks. Nonetheless, certain influential factors demonstrated similar mean scores or a slight mean score difference than other factors. Thus, these factors remained crucial and relevant in facilitating the successful adoption of IR 4.0 technology in smart emergency detection for safety management, regardless of their ranking.

The ranking of the key elements demonstrated the top three factors in descending order: KT3 > KT2 > KT4. Initially, KT3 presented the greatest mean score, and previous studies supported this finding by asserting that KT3 was the primary determinant of smart emergency detection (Guo *et al.*, 2013; Chen *et al.*, 2020). This outcome was followed by KT2, demonstrating that nearly all individuals who underwent training succeeded in enhancing their knowledge, skills, and abilities (Park and Kim, 2013; Jiang *et al.*, 2021). Subsequently, the third-ranking key element was KT4 (Tang *et al.*, 2020). Considering that smart technology was complicated, a manual was essential to improve site safety management.

Each influence factor was observed to be in KT. This observation signified that the respondents claimed that KT should be given paramount importance over another key element. Most scenarios involving technology adoption failure were attributed to insufficient training among the workforce and expert contractors (Li *et al.*, 2015; Othman *et al.*, 2017). Therefore, the federal and state safety and health legislative bodies should emphasise safety training as a baseline measure to enhance workplace safety and health.

This study concluded that KCH, KCO5, and KCO6 were the most minor essential key elements contributing to smart emergency detection. An underlying reason for the low average score of these key elements was that the current emergency detection practice relied on traditional safety management approaches (Costa *et al.*, 2020; Jeelani *et al.*, 2021). This finding revealed a significant research gap in the construction industry due to the unexplored smart emergency detection-based studies using IR 4.0, making these investigations relatively novel (Kasim *et al.*, 2021).

The respondents could possess little exposure to the benefits of IR 4.0 technology adoption for effective safety management. Given that the performance of technology could considerably influence the decision of a company to invest in technology development continuously, the cost implications could occur from the significantly high cost of renting high-end resources for maintenance and long-term worker training (Bello *et al*., 2012; Kim *et al*., 2019; Jung *et al*., 2021).

The successful adoption of the IR 4.0 technology depended on the key elements, significantly impacting smart emergency detection. Conversely, the local safety management practices continued to use the traditional method because IR 4.0 was still in its early stages. Previous studies also emphasised the crucial element of technology training, catalysing efficiency, productivity, and innovation improvements. This observation indicated that IR 4.0 technology could be leveraged to enhance safety management and create a safer workplace for employees. The IR 4.0 technology could also improve safety management as the technology could continue evolving with the dynamic global environment. Consequently, this study denoted that the safety management exposure to IR 4.0 technology must be improved based on the outcomes.

Requirements of Smart Emergency Detection

Table 7 presents the top three requirements of the overall ranking based on the mean score, which are smart systems using a wireless network (RC1), good cellular network connection (RC2), and ability to communicate with technology and smart products (RC3). Even though the factors were associated with a mean score of 4.4, most results fell within the range of 4 on the respondent's "relevant" scale. These factors could significantly influence the requirements. In contrast, the least three essential requirements (mean score of 4.2) contributing to smart emergency detection were capabilities to maintain quality operation (RA1), smart self-monitoring in real-time conditions (RSS1), and automation of the control system (RSS2). Despite the findings revealing that three requirements with a mean score of 4.4 were observed, most results fell within the range of 4 on the respondent's "relevant" scale. These factors could substantially impact the requirements.

Table 7. Rank summary of the requirements for smart emergency detection in safety management

No.	**Item**	**Mean**	**Rank**	**Overall rank**
	Smart, Self-Monitoring, and Control (RSS)			
RSS3	Adaptable to specific circumstances	4.3767	1	4
RSS4	Ability to measure state and environmental conditions	4.3163	2	15
RSS2	Automation of the control system	4.2837	3	17
RSS1	Smart self-monitoring in real-time conditions	4.2372	4	18

	Increased Agility (RA)			
RA4	Alert the event occurs at the construction site	4.3635	1	5
RA3	Most accurate and timely information	4.3628	2	6
RA2	Capabilities for delivery operation	4.3070	3	14
RA1	Capabilities to maintain quality operation	4.2233	4	19
	Better Connectivity (RC)			
RC1	Smart systems using a wireless network	4.4584	1	1
RC2	Good cellular network connection	4.4558	2	2
RC3	Able to communicate with technology and smart products	4.4326	3	3
	Sustainability (RS)			
RS5	Control environmental conditions	4.3616	1	7
RS6	Implement smart to respond automatically	4.3581	2	8
RS4	Encourage and stimulate eco-friendly transportation	4.3419	3	10
RS3	Energy-saving construction technology	4.3209	4	13
	Ease of Use (RE)			
RE1	Minimise the complexity of the system	4.3367	1	11
RE2	Create a user's experience when using a system	4.3049	2	16
	Consistent Self-Registration (RCS)			
RCS1	Register system systematically to internal "observers"	4.3433	1	9
RCS2	Real-time update database system	4.3242	2	12

Among the influential factors of the requirements for this study, RC1 demonstrated the highest mean score. This outcome was followed by RC2, in which respondents agreed that connectivity was the paramount and crucial requirement for emergency detection (Anwar *et al*., 2017). A unified digital ecosystem was also being established through the internet, enabling rapid access to critical data and information in the cloud for optimal coordination of activities. On the contrary, RA1, RSS1, and RSS2 were identified as the least significant requirements for smart emergency detection. This observation suggested that technological functions should implicate the reduction of complexity to facilitate easy access to the applied technology configurations.

Further expansion of IR 4.0 in emergency system technologies was necessary for practical adoption. Nevertheless, specific requirements for deploying IR 4.0 (safety management in the construction sector) could impact intelligent emergency detection. Previous studies also expressed concerns about the extent to which the requirements of technological connectivity drivers could facilitate manufacturers to collect and analyse large-scale data from multiple sources. This process required optimal production processes, product quality, and minimal downtime. Thus, the interoperability between different devices and systems in this framework could render their integration into a single, connected ecosystem more seamless.

Significant Key Element and Requirement Findings for Smart Emergency Detection Using IR 4.0 Technology

This study revealed significant findings on the key elements and requirements for smart emergency detection using IR 4.0 technology in enhancing safety performance. A total of 44 key elements were identified and organised into ten groups of key elements for smart emergency detection using IR 4.0 technology. The KT3 in KT was the top priority in using IR 4.0 technology for effective smart emergency detection. In contrast, KCH2 in KCH presented the lowest rank of 44. This finding emphasised that patent infringement issues in adopting IR 4.0 technology had a minimal effect on smart emergency detection.

A total of 19 requirements were established and grouped into six construct groups for smart emergency detection based on IR 4.0 technology. This study then identified RC1 in RC as the top priority. The requirements for establishing a wireless network using IR 4.0 technology could be successfully executed to enable smart emergency detection. Additionally, RA1 (19th rank) was observed in RA. Therefore, adopting IR 4.0 technology in smart emergency detection systems allowed for the maintenance of operational quality with fewer constraints.

The ranking identification of the key elements and requirements for smart emergency detection using IR 4.0 technology provided valuable guidance to construction industry practitioners (particularly contractors). These practitioners could select the appropriate IR 4.0 technology types (VR, IoT, cloud computing, AI, and big data) to enable smart emergency detection and improve construction safety. The construction industry stakeholders could also use the rankings of the key elements and requirements as a checklist to establish safety management protocols for construction projects.

Policymakers, stakeholders, and safety professionals could obtain valuable insights from the key element and requirement rankings. This information could help them make better-informed decisions and develop strategies enhancing IR 4.0 technology adoption in smart emergency detection. Consequently, this process could contribute to a favourable perception of smart emergency detection.

CONCLUSION

This study successfully presented significant findings regarding key elements and requirements for smart emergency detection using IR 4.0 technology. The analysis revealed three primary key elements (KT3, KT2, and KT4) and requirements (RC1, RC2, and RC3), with mean scores of 4.4. These outcomes demonstrated the substantial influence of the primary key elements and requirements on smart emergency detection. Consequently, each key element and requirement held significance and could influence smart emergency detection in future studies.

Future studies should explore the correlation between key elements and requirements in IR 4.0-enabled smart emergency detection systems. A smart emergency framework should also be conducted, such as empirical and case studies involving active Malaysian construction environments. Overall, the ranking knowledge of key elements and requirements obtained in this study could empower stakeholders, specifically in developing countries (Malaysia). This knowledge could effectively identify emergencies by incorporating cutting-edge IR 4.0 technology for the sustainability of the building sector.

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