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DEVELOPMENT OF A SURVEY QUESTIONNAIRE ON INDUSTRY 4.0 SAFETY CONTROLS IN MALAYSIAN MANUFACTURING INDUSTRIES

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Abstract:

The increasing use of digital technologies in manufacturing is transforming occupational safety and health (OSH) practices. However, structured instruments for assessing how individual Industry 4.0 (IR4.0) technologies are applied as preventive safety controls remain limited. This study developed and conducted a preliminary assessment of a multi-section survey questionnaire for examining IR4.0-enabled safety controls in Malaysian manufacturing industries. A domain-driven approach was used to map nine IR4.0 technology domains to seven grouped occupational-risk areas: slips, trips and falls; machinery accidents, cuts and lacerations; work-related musculoskeletal disorders; heat-related illness; electrical shocks and fire accidents; noise exposure and eye injuries; and chemical or biological exposure. Expert content validity was assessed through an independent review by ten subject matter experts. The final

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questionnaire comprised organisational background questions, awareness and implementation questions, 64 dichotomously coded technology-specific application items, 18 technology-specific effectiveness and wider-application statements, and five general statements concerning implementation effects and challenges. Following ethical approval, a pilot study involving 30 respondents was conducted, and the 64 core application items were analysed using the dichotomous Rasch Measurement Model. Person reliability was 0.86, while item reliability was 0.75. Person measures averaged −1.70 logits and ranged from −3.50 to 0.45 logits, whereas item measures averaged 0.00 logits and ranged from −2.33 to 2.18 logits. These findings provide preliminary support for the wider administration of the instrument. The questionnaire offers a structured foundation for large-scale assessment of IR4.0-enabled OSH applications, although further analysis using the main-study dataset is required to examine dimensionality, item targeting, domain-specific functioning, differential item functioning, and measurement stability.

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Keyword:

Accident Risk Control; Industry 4.0; Manufacturing Safety; Occupational Safety and Health; Questionnaire Development; Rasch Measurement Model

Introduction

Occupational accidents continue to be a significant concern in manufacturing, despite regulatory enforcement, engineering controls and formal safety-management systems. Slips, trips and falls; machinery accidents, cuts and lacerations, work-related musculoskeletal disorders, chemical exposure and electrical hazards still cause incidents in complex production environments. This persistence suggests that traditional occupational safety and health (OSH) practices, which often rely on rules, periodic inspections and post-incident investigation, may not fully address hazards that change quickly or arise from connected systems. Industry 4.0 (IR4.0) technologies are also changing the way manufacturing work is organised and monitored. Connected machines, smart sensors, data analytics, automation, and human-machine interfaces can help with hazard identification, detection of abnormal conditions, maintenance planning, and reduction of workers' exposure to hazardous tasks (Badri et al., 2018; Brocal et al., 2019; Sony, 2018). Previous research has shown the potential of wearable sensors, smart machinery, collaborative robots and safety data systems in supporting accident prevention and emergency response (Cagno et al., 2024; Kadir & Broberg, 2021; Svertoka et al., 2021). However, IR4.0 technologies may also introduce risks related to system complexity, cybersecurity, mental workload, work stress and human–robot interaction (Jiang et al., 2024; Leso et al., 2018; Park et al., 2023). The safety value therefore depends on organisational readiness, proper system integration and workers' ability to use the technologies safely.

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A key limitation is the lack of a structured instrument for comparing how individual technologies are used to control specific occupational risks. Many existing studies remain conceptual or focus on individual technologies and case studies (Jiang et al., 2024; Lindholm et al., 2024). Accident frequency and injury severity remain important, but these indicators do not show how digital technologies are being used as preventive controls before an incident occurs.

Accordingly, this study aimed to: (1) develop a structured questionnaire that maps nine IR4.0 technology domains to common occupational-risk areas in manufacturing; (2) describe the structure and response formats of the questionnaire; and (3) examine the preliminary reliability and functioning of the 64 core application items using the Rasch Measurement Model.

Literature Review

Occupational Accident Risks in Manufacturing

Occupational accidents in the manufacturing sector are often the result of the interplay between machines, hazardous materials, physical demands of work, production pressure, decisions made by the operator and organisational control. As a result, slips and falls, entanglement with machinery, musculoskeletal strain, heat stress, electrical contact and chemical exposure are rarely the result of a single failure (Hale et al., 2012; Lindholm et al., 2024; Liu et al., 2023). IR4.0 technologies can improve occupational-risk control through real-time monitoring, remote access, automated warnings, and data-supported decision-making. However, the usefulness depends on the response of workers and organisations to the information generated. Hence assessments should distinguish between the generic use of a technology and its actual use for specific safety functions.

Industry 4.0 Technologies and OSH Applications

IR4.0 technologies can support workplace safety and health in several ways. Sensors and wearable devices, for example, can monitor workplace temperature and noise levels, worker movement and posture, equipment condition, and changes in production operations. Big Data Analytics can help organisations identify patterns in accident records and exposure data. Cloud platforms and integrated systems can make it easier to collect, store and share safety data. Autonomous robots can also reduce workers' direct exposure to hazardous or repetitive tasks. Simulation and digital twin technologies can also be used for training, process testing and emergency planning (Lindholm et al., 2024; Nioata et al., 2025). These examples show that each technology has a different role in the safety system. IoT is generally associated with real-time monitoring and early warning, whereas Big Data Analytics is more useful for identifying patterns, trends and recurring risk factors. Augmented Reality can support workplace safety training and provide visual instructions. Cloud Computing and System Integration facilitate the collection of safety information and make it easier for organisations to access and share this information. Simulation and Digital Twin technologies allow hazardous events to be examined in a simulated environment before they occur in actual operations. Cybersecurity is also important for protecting connected safety systems and information against unauthorised access, disruption or misuse (Badri et al., 2018; Lindholm et al., 2024; Park et al., 2023). The benefits of these technologies do not depend on the technology alone. The performance is also affected by organisational readiness, worker acceptance, ease of use, data quality and integration with existing safety measures. Poorly designed digitalisation may create additional problems related to cybersecurity, automation failure and human–machine interaction (Kamble et al., 2018; Leso et al., 2018; Sony & Naik, 2020). Previous studies have described the potential of IR4.0. However, most research has focused on productivity, digital readiness or general technology adoption. The application of technologies to control specific occupational risks in diverse organisational settings has received little attention.

Research Gap

While interest in IR4.0 and occupational safety is growing, many current studies continue to use conceptual discussions, descriptive case studies, or generic measures such as digital maturity, safety culture, and technology readiness (Badri et al., 2018; Brocal et al., 2019; Sony, 2018). Existing studies provide limited evidence on which technologies are used to control specific occupational risks and the extent to which these safety functions are implemented (Lindholm et al., 2024; Park et al., 2023). Accident reports and compliance checklists tend to focus more on outcomes after an incident than on the use of preventive digital controls. This limitation shows the need for a structured technology-specific questionnaire that differentiates between technology adoption, practical safety applications, perceived effectiveness and implementation challenges. The present study addresses this gap by developing 64 core application items that map nine IR4.0 technology domains to seven grouped occupational-risk areas.

The core application items were examined for preliminary functioning using the Rasch Measurement Model. This places person and item measures on the same logit scale, allowing the reported organisational implementation to be compared with the relative difficulty of endorsing each application. In this study, person measures reflect the extent of IR4.0-enabled OSH applications reported by the respondents, whereas item measures represent the relative likelihood that individual IR4.0-enabled OSH applications were endorsed by respondents. The pilot analysis aimed to evaluate preliminary reliability and measurement behaviour rather than full psychometric validation (Bond & Fox, 2015; Boone et al., 2014).

Methodology

Research Design

This study used an instrument-development design to translate IR4.0 safety applications into measurable questionnaire items for comparison across manufacturing organisations (Boateng et al., 2018; DeVellis, 2017). The study covered questionnaire development, pilot administration, and preliminary Rasch assessment. Item development drew on the peer-reviewed literature on IR4.0 technologies, OSH risk management, manufacturing incidents, and technology adoption (European Agency for Safety and Health at Work [EU-OSHA], 2023; Frank et al., 2019; Kagermann et al., 2013). Nine IR4.0 technology domains and seven grouped occupational-risk areas were identified. The development process involved the following steps: domain selection, technology-risk mapping, item generation, questionnaire structuring, ethical approval, pilot-testing and final survey preparation. Ethical approval was obtained from the Research Ethics Committee (REC) before participant recruitment and data collection (REC/08/2024 (PG/MR/358)). The pilot questionnaire contained 64 core application items and was administered to 30 respondents. Following the pilot study, wording, instructions, bilingual presentation, and response layout were refined, while all 64 core application items were

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retained. This article reports only the development of the questionnaire and its preliminary pilot assessment.

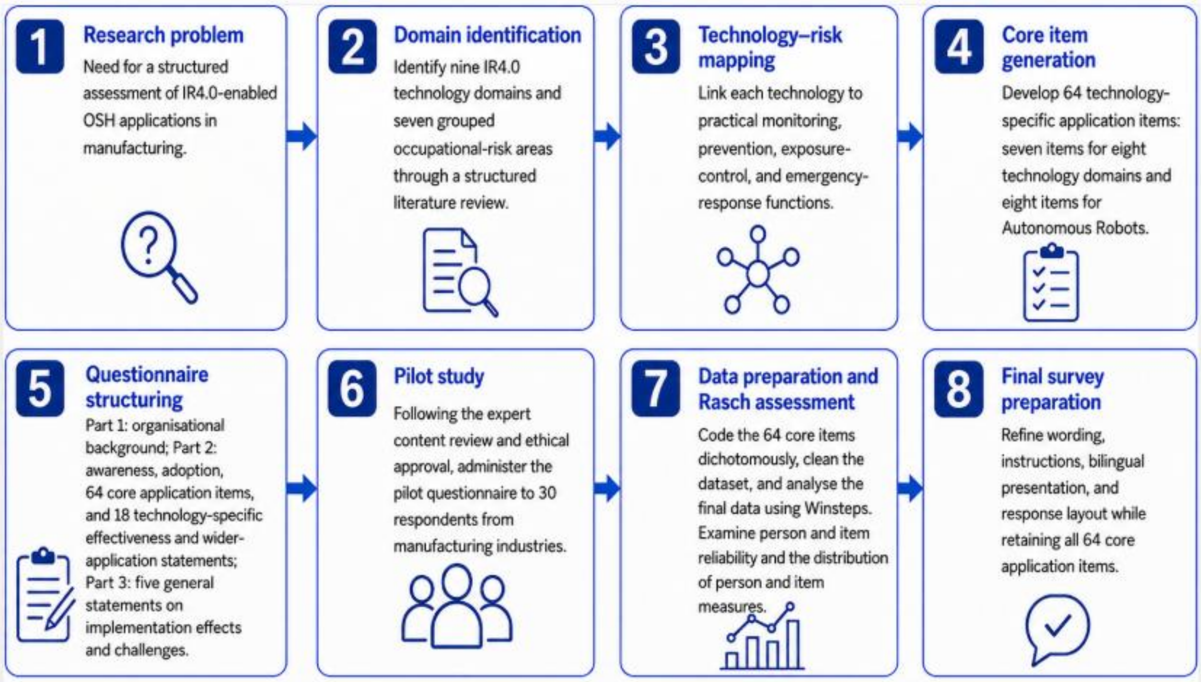

Figure 1: Instrument Development, Ethical Approval, Pilot Administration, And Preliminary Rasch Assessment Workflow For The IR4.0-Enabled OSH Survey.
Source: Authors' Illustration

Questionnaire Development Procedure

The questionnaire was developed through three main stages within the broader workflow shown in Figure 1, based on accepted principles of survey design (Artino et al., 2014; DeVellis, 2017). First, nine Industry 4.0 (IR4.0) technology domains and seven grouped occupational-risk areas were selected and explicitly described. Second, each technology domain was mapped to applicable safety-control functions, such as real-time monitoring, risk prediction, exposure reduction, remote access, visual guidance, substitution of hazardous tasks, simulation, information integration, and system protection. Third, these technology-enabled safety functions were converted into 64 core application items. Eight technology domains contained seven items each, while the Autonomous Robots domain contained eight items.

The questionnaire also included 18 technology-specific effectiveness and wider-application statements rated on a five-point Likert scale. Two statements were created for each of the nine IR4.0 technology domains to measure perceived effectiveness and potential for wider use. Five additional general statements addressed cybersecurity threats, job security, implementation cost, technological complexity, and product quality. The questionnaire was developed in both English and Bahasa Melayu and was divided into three main sections.

Expert content validity was assessed through independent review by ten subject matter experts who were selected purposively based on the academic qualifications, professional experience, industrial exposure, and expertise in the areas of manufacturing, Industry 4.0, occupational safety and health, and risk management. The size of the panel was within the range generally recommended for expert-based content evaluation (Yusoff, 2019). Seven panel members were academics with practical experience relevant to the study and expertise in manufacturing systems, engineering and Industry 4.0. The other three were a safety officer, an industry practitioner, and an occupational safety and health coordinator. Overall, the panel provided a balance of academic knowledge and practical industrial experience, which allowed the questionnaire items to be viewed from a theoretical, technical, safety, manufacturing and operational standpoint. All experts evaluated the questionnaire independently using common evaluation criteria and the same standardised assessment form. The review focused on the relevance, clarity, suitability and practical applicability of the questionnaire items.

Following the expert content review, the questionnaire was piloted. The wording, instructions, bilingual presentation, formatting and response structure were refined based on feedback from pilot participants and an analysis of response patterns. These modifications enhanced clarity and usability of the questionnaire without removing or altering the 64 core application items.

Conceptual Framework for Instrument Development

The conceptual framework linked the nine IR4.0 technology domains to practical OSH functions and seven grouped occupational-risk areas. It treated the technologies as tools for monitoring, prediction, guidance, automation, information integration, simulation, and system protection. The framework also recognised that implementation is affected by organisational context, workforce readiness, system integration, cost, and cybersecurity governance.

Table 1: Distribution of the 64 Core Application Items by IR4.0 Technology Domain

IR4.0 Technology Domain	Core Items	Primary OSH Coverage	Illustrative Functions
Internet of Things (IoT)	7	Real-time monitoring across the seven grouped occupational-risk areas	Workplace conditions, machinery, worker movement, temperature, noise, PPE use, and hazardous substances.
Big Data Analytics	7	Pattern and trend analysis across the seven grouped occupational-risk areas	Accident causes, machine and worker behaviour, ergonomic risk, electrical/fire incidents, noise, chemical exposure, and OSH data.
Additive Manufacturing	7	Safer components and customised protective equipment	Anti-slip equipment, machine/electrical parts, noise-control products, cooling PPE, fire-resistant parts, eyewear, and chemical protection.
Augmented Reality	7	Visual guidance, hazard information, and training	Hazard visualisation, lifting guidance, machinery/electrical instructions, fire information, infrastructure visualisation, noise feedback, and virtual training.
Autonomous Robots	8	Substitution of hazardous and repetitive tasks	Cleaning, inspection, cutting, heavy lifting, hot work, electrical inspection,

IR4.0 Technology Domain	Core Items	Primary OSH Coverage	Illustrative Functions
			fire response, noisy-area work, and chemical/biological handling.
Cloud Computing	7	Data centralisation, remote monitoring, and alerts	Storage and analysis of sensor, machine, fire, worker-movement, noise, temperature, and chemical-safety information.
System Integration	7	Coordination of monitoring and control systems	Floor maps, machine data, workload monitoring, temperature control, electrical systems, noise sensors, emergency response, and PPE management.
Simulation / Digital Twin	7	Virtual testing, training, and scenario analysis	Facility layout, hazardous-area training, process testing, electrical modelling, fire scenarios, noise simulation, and chemical-process modelling.
Cybersecurity	7	Protection of connected safety systems and information	Sensors, manufacturing systems, worker and chemical data, electrical infrastructure, IoT devices, and safety information.
Total	64		

Source: Authors' Analysis

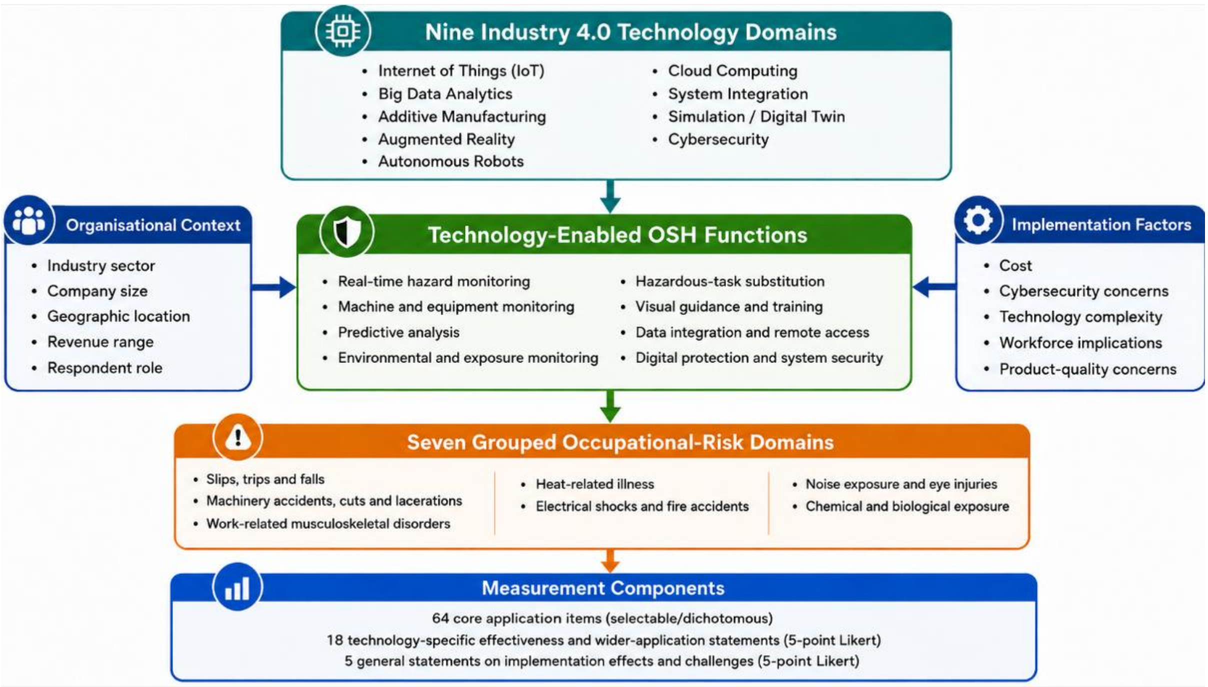

Figure 2: Conceptual Framework Linking IR4.0 Technologies, Technology-Enabled OSH Functions, Occupational-Risk Areas, And Questionnaire Measurement Components.

Source: Authors' Illustration

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Figure 2 shows how the technology domains, safety functions, risk areas, organisational context, and measurement components are connected. The 64 core application items recorded whether specific technology-enabled safety functions were reported. The 18 technology-specific effectiveness and wider-application statements and five general statements measured perceptions using a five-point Likert scale. In the Rasch analysis, the person measure represented the extent of reported organisational IR4.0-enabled OSH application and was not interpreted as individual professional ability.

Questionnaire Structure

The questionnaire had three parts. Part 1 collected organisational and respondent background information. Part 2 covered IR4.0 awareness and implementation, 64 core application items, and 18 technology-specific effectiveness and wider-application statements. Part 3 contained five statements on wider implementation effects and challenges.

Table 2: Overview of the Structured Questionnaire for Assessing IR4.0-Enabled Occupational Accident-Risk Control

Questionnaire Section	Purpose / Focus	Key Content	Response Format
Part 1: Business Background	Organisational and respondent profiling	Company name, respondent role, location, industry type, workforce size, and revenue range	Nominal / categorical
Part 2: IR4.0 Implementation and Accident Risk Control	Assessment of awareness, adoption, practical OSH applications, and technology-specific effectiveness	Awareness and implementation status; nine IR4.0 domains; 64 core application items; 18 technology-specific effectiveness and wider-application statements	Categorical and yes/no items; 64 dichotomously coded application statements; 18 five-point Likert statements
Part 3: Effects and Challenges of IR4.0 Implementation	Assessment of cross-cutting implementation effects and concerns	Cybersecurity threats, job security, implementation cost, technological complexity, and product quality	Five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree)

Source: Authors' Analysis

Response Formats and Measurement Scale

The response format matched the type of information collected. Background questions were nominal or categorical, while awareness and technology-adoption questions used yes/no or categorical responses. The 64 core application items were selectable responses and were coded dichotomously for Rasch analysis. The 18 technology-specific effectiveness and wider-application statements and five general statements used a five-point scale from 1 (Strongly Disagree) to 5 (Strongly Agree) (Likert, 1932; Joshi et al., 2015). The questionnaire was therefore not treated as a single five-point Likert scale.

Data Preparation and Analysis

The raw pilot responses were entered into Microsoft Excel. The 64 core application items were coded dichotomously, with selected applications coded as 1 and non-selected applications coded as 0. The dataset was checked for duplicate records, incomplete responses, missing values, and coding errors. Following data screening and cleaning, all 30 completed responses were retained for the Rasch analysis. The final dataset of 30 respondents across 64 items was imported into Winsteps and analysed using the dichotomous Rasch Measurement Model. The Rasch analysis examined person reliability, item reliability, and the distribution of person and item measures. Person measures represented the extent of reported organisational IR4.0-enabled OSH application. Because the pilot involved only 30 respondents, the findings were treated as preliminary rather than definitive psychometric validation (Bond & Fox, 2015; Boone et al., 2014).

Pilot Study Procedure

Ethical approval was obtained before the pilot study began. The questionnaires were sent out via e-mail to manufacturers. The invitations were primarily directed toward safety officers, engineers, and other employees who have some form of connection with manufacturing operations; occupational safety & health; or technology implementation. A total of 30 complete responses from various manufacturing industries were utilized in this pilot study. The primary purpose of conducting this pilot study was to assess whether the questionnaire could be administered in a timely manner; if the questions were understandable; and if the method of administering the questionnaire (response and data collection) functioned as expected. Additionally, the preliminary reliability of the instrument was assessed prior to widespread distribution of the questionnaire. Several changes were made to the wording, instructions, bilingual format, and layout of the response options after reviewing the feedback received and assessing response patterns. However, all 64 core application items remained intact.

Results

Questionnaire Development Outcome

The outcome was a bilingual, three-part questionnaire linking nine IR4.0 technology domains with seven grouped occupational-risk areas. The final questionnaire contained organisational and awareness questions, 64 dichotomous core application items, 18 technology-specific effectiveness and wider-application statements, and five general Likert statements. All 64 core application items were retained after the pilot. The expert content evaluation focused on relevance, clarity, appropriateness and practical applicability of the questionnaire items. The questionnaire was revised based on the feedback of the ten subject matter experts concerning its phrasing, terminology, instructions and presentation. These revisions improved the clarity and contextual appropriateness of the instrument, while retaining the general structure and all 64 core application items for pilot administration.

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Preliminary Rasch Results

Responses from 30 pilot participants were used to assess the 64 core application items. Table 3 provides a summary of the person and item reliability values and the distribution of person and item measures. The person reliability of 0.86 provided a preliminary indication that the instrument could distinguish between respondents reporting different levels of organisational IR4.0-enabled OSH application. Item reliability of 0.75 showed moderate stability of the item hierarchy in the small pilot sample. The mean person measure of −1.70 logits was lower than the item mean of 0.00 logits, showing that respondents tended to report fewer applications than represented by the average item measure. Person measures ranged from -3.50 to 0.45 logits and item measures ranged from -2.33 to 2.18 logits. However, the precision and stability of item calibration were limited by the small sample. These results therefore do not establish unidimensionality or comprehensive psychometric validation.

Table 3: Summary of the Preliminary Rasch Results for the 64 Core Application Items

Measurement Index	Person	Item
Reliability	0.86	0.75
Mean measure (logits)	-1.70	0.00
Maximum measure (logits)	0.45	2.18
Minimum measure (logits)	-3.50	-2.33

Source: Authors' Analysis

Discussion

The developed questionnaire was designed to capture two related aspects of IR4.0-enabled occupational safety practices. First, it identifies the applications that organisations report using to control workplace risks. Second, it examines respondents' perceptions of the effectiveness of these technologies, together with the challenges that may affect the implementation. This structure allows the instrument to assess not only whether a particular technology is present within an organisation, but also how it is perceived in terms of its practical safety value and wider application. The main contribution of the questionnaire lies in its explicit mapping of nine IR4.0 technology domains to seven grouped occupational-risk areas. Rather than treating digitalisation as a single organisational construct, the instrument recognises that different technologies may perform different safety functions and may not be equally relevant to every type of occupational risk. For example, some technologies are more closely associated with real-time monitoring and early warning, while others support data analysis, virtual testing, training, system connectivity or the protection of safety-related information. Organising the questionnaire in this way provides a more detailed basis for examining how specific IR4.0 technologies are applied across different risk areas. It also supports a clearer comparison of technology use, perceived effectiveness and implementation challenges within the broader context of occupational safety and health.

Contribution of the Technology-Specific Questionnaire

The 64 core items support comparison of reported applications for machinery safety, environmental monitoring, ergonomic risk reduction, emergency preparedness, exposure control, and protection of connected systems. The 18 technology-specific effectiveness and wider-application statements and five general statements were included to capture perceptions of effectiveness, potential wider application, cybersecurity, job security, implementation cost, technological complexity, and product quality. Separating reported implementation from perception avoids combining different constructs into one score and addresses a recurring limitation in IR4.0-OSH research (Badri et al., 2018; Brocal et al., 2019; Sony, 2018).

Interpretation of the Preliminary Rasch Results

Person reliability of 0.86 suggests that the pilot instrument could distinguish respondents reporting different levels of organisational application. Item reliability of 0.75 provides moderate preliminary support for the stability of the item hierarchy. The lower mean person measure (−1.70 logits) compared with the item mean (0.00 logits) suggests that several IR4.0-enabled OSH applications included in the questionnaire were not yet widely reported by the pilot respondents. This may reflect uneven adoption of advanced IR4.0-enabled OSH practices. It was also expected because the instrument was designed to cover both commonly used and emerging safety applications. Nevertheless, the interpretation remains tentative because the pilot sample was small and was not representative of the wider manufacturing population.

Study Limitations and Future Validation

This study has several limitations. The pilot involved only 30 respondents, which limits the precision and stability of item calibration. The core items recorded reported applications and did not verify whether the technologies reduced actual accidents, injuries, or exposure. The nine technology domains and seven grouped occupational-risk areas may also contain more than one underlying dimension. Further analysis using the larger main-study dataset should examine item fit, targeting, dimensionality, differential item functioning, domain-specific performance, and agreement with industrial verification or objective safety indicators.

Conclusion

This study developed a bilingual, multi-section questionnaire to examine the use of Industry 4.0 (IR4.0) technologies as occupational accident-risk controls in the manufacturing sector. The instrument was designed to capture both reported organisational applications of IR4.0-enabled safety controls and respondents' perceptions of the effectiveness, wider application and implementation challenges. It consists of 64 core application items, 18 technology-specific effectiveness and wider-application statements, and five general implementation statements. These components are organised across nine IR4.0 technology domains and seven grouped occupational-risk areas, allowing the instrument to examine digital safety practices in a more detailed and structured manner.

A key feature of the questionnaire is the explicit connection between individual IR4.0 technologies and specific occupational-risk areas. Rather than treating digitalisation as a single organisational construct, the instrument recognises that different technologies may serve different safety functions. Some technologies may support real-time monitoring and early warning, while others may contribute to data analysis, virtual testing, system integration, safety training or the protection of connected information. This structure provides a basis for examining how organisations apply different technologies to manage occupational accident risks and how these applications are perceived by individuals involved in manufacturing operations, engineering, technology and occupational safety and health.

The questionnaire was pilot tested with 30 respondents. The Rasch analysis produced a person reliability value of 0.86 and an item reliability value of 0.75. The person reliability result indicates that the instrument was able to distinguish between respondents reporting different levels of organisational IR4.0 safety-control implementation. The item reliability result suggests that the relative ordering of the application items was moderately stable within the pilot sample. However, these findings should be interpreted cautiously because they were obtained from a small pilot sample and represent an early stage of instrument evaluation.

Overall, the pilot findings provide preliminary support for the wider administration of the questionnaire in the main study. They indicate that the instrument has the potential to generate structured information on the implementation of IR4.0 technologies for occupational accident-risk control in manufacturing. Nevertheless, further validation using the main-study dataset is required before stronger conclusions can be drawn regarding the instrument's measurement quality, construct structure and broader applicability. Future analysis should therefore examine the performance of the questionnaire using a larger and more diverse sample of manufacturing organisations. This would provide a stronger basis for evaluating the stability of the items, the consistency of respondent measures and the suitability of the instrument for assessing IR4.0-enabled occupational safety practices across different organisational settings.

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Ethics Statement: The present study was approved by the Research Ethics Committee of Universiti Teknologi MARA (UiTM), Malaysia (approval reference REC/08/2024 (PG/MR/358)). Ethical approval was obtained before the pilot study. Participation was voluntary and informed consent was obtained prior to the administration of the questionnaire. Participants were informed of the purpose of the study, their right to refuse participation or to withdraw and the confidentiality of the information provided. No directly identifiable personal data, such as respondent names, were collected. Company-level information and questionnaire responses were handled confidentially, managed securely, and reported only in aggregate form for research purposes.

Author Contribution Statement: Ameran Saiman: Conceptualisation, methodology, questionnaire development, literature review, data interpretation and original manuscript preparation. The research was supervised by Norliana Mohd Abbas who provided guidance in study design, methodology, validation and overall development of the manuscript. Alias Mohd Saman was the co-supervisor and involved in methodological guidance, interpretation of the findings and review of the manuscript. Azli Abdul Razak critically revised the manuscript and provided helpful suggestions to improve its scholarly quality. Nurul Syuhada Khusaini was involved in data collection, data analysis and interpretation of results. All authors read and approved the final version of the manuscript before submission.

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