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Safety Challenges in Optimising IBS Precast and Lifting Machinery: Insights from Malaysian Construction Stakeholders

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ABSTRACT

This study examines the challenges associated with optimising Industrialised Building Systems (IBS) and lifting Machinery that impact safety within the Malaysian construction Industry. To optimise the IBS precast, a comprehensive strategy is required for both the concrete processing area and the line processing area, such as the Rebar processing area. Developing hypotheses about the impact of optimisation is aided by the ongoing adoption of underlying ideas, such as Design for Manufacturing and Assembly (DfMA), in the context of safety challenges. The primary objective is to identify any safety concerns with IBS precast goods and the lifting apparatus in the IBS prefabricated processing area. Eight people in Selangor and Johor responded to semi-structured interviews after twelve invitations were sent out for a preliminary survey and collected by using snowball sampling. The results and findings that concentrate on the theme in the safety issues are Material Handling Hazard, Standardisation & Operation Capacity, and Lifting Machinery Safety Gap, which have consequences for worker safety training for the IBS precast products and lifting machinery operations.

INTRODUCTION

The concept of Sustainable Development Goals (SDGs) comes from the idea of building a global framework for development that balances economic growth, social inclusion, and environmental protection. They were adopted by all United Nations Member States in 2015 as part of the 2030 Agenda for Sustainable Development, with a timeline up to 2030. According to Jayawardana et al. (2025), Josa et al. (2025),

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Ferreira et al. (2021), and Reicherbach et al. (2021), the integration of IBS precast systems within the construction industry directly supports multiple SDGs, particularly SDG 3 (Good Health and Well-being), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production).

The construction industry has undergone notable advancements worldwide, propelled by the integration of innovative technologies that significantly influence Sustainable Development Goal 9, which focuses on Industry and Innovation. The idea of using IBS was initiated from the concept of manufacturing (Koskela, 2000). Recurring processes had been noted in both IBS and manufacturing. The relationship for A Safety between SDGs and IBS is shown in Table 1, as mentioned below.

Table 1. Relationship between SDGs with Safety Challenges in the IBS Precast

No.	Sustainable Development Goal (SDG)	IBS Precast Contributions	Safety Challenges IBS Precast Relationship with SDGs	Citations
1.	SDG3: Health and Well-being	Reduces on-site accidents via prefabrication	Requires robust safety protocols for handling heavy elements and connections	Jayawardana et al., 2025; Joshi et al., 2020; Khan G.A. & Ali A., 2025; Guaygua et al., 2023
2.	SDG8: Decent Work	Promotes safer, more controlled work environment	Automation and new methods introduce new safety needs	Jayawardana et al., 2025; Reichenbach S. & Kromoser, B., 2021; Joshi et al., 2020;
3.	SDG9: Industry & Innovation	Drives adoption of advanced, efficient construction	Demands innovation in safety management and resilient design	Jayawardana et al., 2025; Khan G.A. & Ali A., 2025; Guaygua et al., 2023; Xiao et al., 2024
4.	SDG12: Responsible Consumption	Minimises waste, uses recycled materials.	Safety handling and quality control of new materials is essential	Jayawardana et al.2025; Ferreira, F. P. V., & Oliveira, M., 2021; Reichenbach S. & Kromoser, B., 2021; Sua-iam et al., 2023

Source: Authors (2025)

Several comparative studies have been conducted between IBS Precast and conventional construction (CC). The Malaysian construction sector continues to have low productivity due to a lack of innovation and technology adoption in construction methods, as well as a reliance on unskilled personnel (CIDB, 2015). A study by Ahmed et al. (2019) clearly shows the use of workers in the rebars and concreting processing area to produce IBS Precast products.

Table 2. Sub-Activity in IBS Production Line

Item	Sub- Activities	Duration per Components (min)	Worker	Remarks
1.	Open storage		1	For uncut steel bars
2.	Manually carrying the steel bars to the cutting area		1	The distance to cutting area is nearer
3.	Cutting steel bars	15	1	Both of activities of cutting and bending referred to steelwork schedule not as production schedule
4.	Bending steel bars	15		
5.	Placement and storage of steel bars			Cut and bended of the steel bars that are not scheduled to be used immediately

6.	Manually carrying the steel bars to the fabrication area	18		19 return trips (from bending area to fabrication area)
7.	Placed nearby fabrication area	18		
8.	Fabrication 1	45	2	Each fabrication area produced 9 sets of completed reinforcement cages, hence totalling up to 27 sets of cages
9.	Fabrication 2	45	2	
10.	Fabrication 3	90	1	
11.	Inspection	10		QA and QC supervision (production team)
12.	Rework	1440 or 2880		Adjustment (24 hours), if required. Not a daily problem, but rectification is demanded upon occurrence
13.	Placement at storage (Storage 2)	1440 or 2880		
14	Waiting for placement	1440 or 2880		Long period of waiting
Total Number of Steelwork Team Members				
15.	Lifting	6	7	The operation for the next day is to place the fabricated cage into the steel mould
16.	Tightening, as well as placing spacer chair and ducting pipes	6	2	
17.	Placing to the mould	4	2	Installation of the other side of the mould
Total Number of Concreting Team Members			2	

Source: Authors (2025)

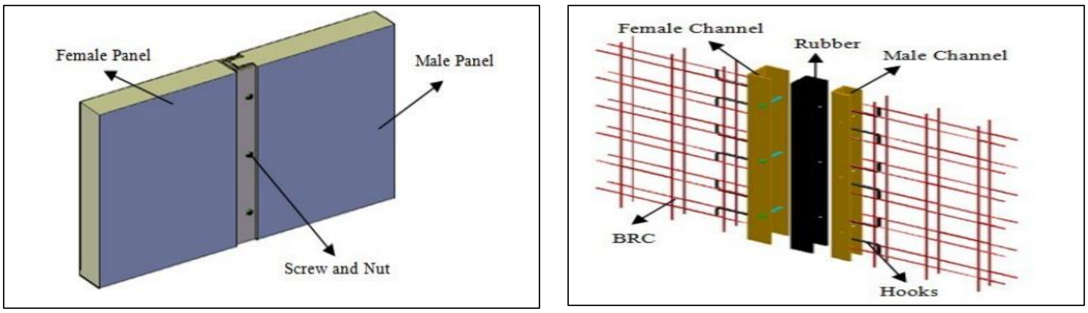

Fig. 1. (left) Assembly Elements Include Rebars and Concrete (Right) Rebars Components. IBS Precast Can Best Described into The Rebars Production Area and Concreting Production Area. Below Are the Description for The Machinery Involved in The Both Production Area.

Source: Authors (2025)

Machinery in the Rebar Production Area

A A wide range of specialised machinery is utilised in the manufacture of rebars and concrete to automate, optimise, and efficiently manage materials. The rebar production area consists of lifting machinery, automated rebar-manufacturing machines, and lastly, cutting and handling machinery. Lifting machinery is an important component in both fields, as it facilitates the movement and placement of heavy materials. Navon et al. (1995) state that components such as cranes, hoists, and other lifting devices are essential for moving heavy rebar bundles and finished products within the production area and to storage or transport locations. Several types of lifting machinery are described in Table 3.

Table 3. Type of lifting machinery in the IBS Rebar Production Area

No.	Crane Types	Key Characteristics	Typical Use in IBS Rebar Productions	Key Features/ Considerations	Citations
1.	Girders Crane	Main girders span the production area, supporting a trolley and hoist	Moving heavy/long rebar bundles and precast girders across the shop floor	High lifting capacity, precise movement, stress analysis of girders is critical for safety	Lima et al., 2024; Rudnev & Lyaturinsky, 2021
2.	Gantry Crane	Girders supported by freestanding legs, mobile on rails or wheels	Outdoor or large indoor yards for long rebar or girders	Flexible placement, suitable for large/irregular loads	Lima et al., 2024
3.	Mobile Crane	Telescopic or lattice boom acts as a movable girder	Lifting and transporting rebar or girders between stations or to storage	Versatile, requires careful lift planning for safety	Guo et al., 2021
4.	Jib Crane	Rotating arm, limited range, compact design	Assisting with localised lifting tasks, such as loading rebar onto machines	Act as Mobile crane but in small area of production x cZ	Fang et al., 2021

Source: Authors (2025)

Machinery in the Concrete Production Area

In the concreting production area consist of concrete mixing and pumping machinery and lastly cutting and lifting machinery. Lifting Machinery: Cranes, hoists, and forklifts, used to lift and position precast concrete elements, reinforcement cages, and other heavy components during production and installation Kim et al. (2023). Several types of lifting machinery in the concreting production area as describe in Table 4.

Table 4. Type of lifting machinery in the IBS Concreting Production Area

No.	Crane Types	Key Characteristics	Typical Use in IBS Concreting Production Areas	Key Features/ Considerations	Citations
1.	Overhead (Bridge) Crane	Fixed rails, spans production area, high lifting capacity; used for moving concrete products within factories or enclosed spaces	Fixed rails, spans production area, high lifting capacity; used for moving concrete products within factories or enclosed spaces	Requires regular maintenance of rails and wheels for reliability	Fang et al., 2021
2.	Mobile Crane	Wheeled or crawler-mounted, flexible movement, moderate to high capacity; used for transporting and installing precast elements	Transporting and positioning precast elements where flexibility and mobility are needed, especially for components requiring movement across the site	Suitable for dynamic or space-constrained sites; can be robotised for automation	Yong, 2023; Xiao, 2025
3.	Mini Crane / Hoist	Compact, low capacity (e.g., 200 kg), portable; ideal for small-scale or remote projects, lifting concrete in confined areas	Handling small precast elements or concrete buckets in confined or remote areas, especially for small-scale or low-rise projects	Cost-effective for small projects; can be locally fabricated and adapted for remote sites	Cim & Bahrun, 2020

Source: Authors (2025)

Design for Manufacturing and Assembly (DfMA)

Design for Manufacturing and Assembly (DfMA) is both a philosophy and a methodology that guide designers to create products that are easy, cost-effective, and efficient to manufacture and assemble. According to Boothroyd (1994), Gao et al. (2019), and Bogue (2012), it emphasises considering manufacturing and assembly requirements from the earliest stages of product design, rather than treating them as afterthoughts. Furthermore, Boothroyd (1994), Gao et al. (2019), and Koraishy et al. (2011) encourage collaboration between design, manufacturing, and assembly teams to ensure that products are optimised for all stages of production. The methodology, as described by Gao et al. (2019), Xie (2013), and Lewis (2015), focuses on reducing the number of parts, simplifying product structures, and designing components that are easy to handle, orient, and join. By addressing potential manufacturing and assembly issues early, Boothroyd (1994), Gao et al. (2019), Lewis (2015), and Bogue (2012) assert that DfMA helps lower production costs, reduce assembly time, improve quality, and minimise defects. Gao et al. (2019), Lu et al. (2020), and Wasim et al. (2020) highlight that DfMA is not just a set of tools but a holistic approach applicable across industries, including construction, where it supports offsite prefabrication and modular assembly. It supports simultaneous consideration of product design, manufacturing processes, and assembly methods, which Boothroyd (1994) and Koraishy et al. (2011) note leads to faster time-to-market and better product outcomes. DfMA transforms traditional design by making manufacturability and assemblability central to the process, resulting in products that are easier, faster, and cheaper to produce and assemble, with higher quality and fewer errors. Finally, Razak et al. (2022), Montazeri et al. (2024), and Thajudeen et al. (2022) mention that standardisation in the early stage for manufacturability and assembly can reduce complexity and enable mass customisation when integrated with IBS Precast and DfMA, as shown in Table 5.

Table 5. Relationship between IBS Precast with DfMA (Optimisation)

No.	Aspects	IBS Precast Focus	DFMA Contributions	Integration Insights	Citations
1.	Design	Modular, standardised, components	Early-stage design for manufacturability mass customisation	Reduces complexity, enables mass customisation	Abd Razak & Murray, 2022; Tuvayanond, 2023; Montazeri, 2024; Thajudeen, 2022
2.	Manufacturing	Off-site, factory – based precast production	Optimisation for ease of fabrication	Minimises errors, improves quality, reduces waste	He et al., 2021; Metvaei, 2025; Wasim et al., 2020; Gao et al., 2019
3.	Assembly	On-site installation of precast elements	Simplified, efficient assembly processes	Shorten construction time, enhance safety	Abd Razak & Murray, 2022; Tuvayanond, 2023
4.	Sustainability	Reduce site waste, improve resource use	Lifecycle optimisation, circularity	Supports sustainability construction goals	Dewagoda et al., 2024; Montazeri, 2024; Abd Razak & Murray, 2022

Source: Authors (2025)

IBS frequently incorporates rebar and concrete production facilities. These two variables are critical for successfully creating prefabricated construction components that meet audit safety standards. Crane-lifted machinery is the most vulnerable to accidents of any type of machinery, with the potential to cause property and life loss (Fang et al, 2019). Lifting apparatus, such as cranes, is commonly used in construction, both on and off-site, which increases the potential of near-miss accidents or fatalities. The Centre for Construction Research and Training (CPWR, 2019) conducted research to uncover global data on crane fatalities, which account for 61% of 632 fatalities (loads colliding with barriers like as power lines, personnel, and structures). According to the DOSH (Department of Occupational, Safety, and Health)

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Malaysia report, Malaysia has 85% more construction accidents than the global average of 15%. According to DOSH (2022), occupational accidents in Malaysia's construction industry are 85% higher than the global average of 15%. DOSH Malaysia anticipates three (3) machinery-related issues in 2020: (1) modes of transportation and lifting equipment, (2) machines, and (3) refrigeration, installations, and electric motors. DOSH Malaysia reported, that 24% of fatalities happened while lifting or moving tools and materials. A.M. Alawag et al. 2021; N. Abas et al. 2021; Mohd Reeza Yusof et al. 2024; mentioned that risk of accident due to lifting higher weight as described in Table 6.

Table 6. Safety Challenges in the IBS Precast and lifting Machinery

No.	Safety Challenges	Key Findings and Issues	Citations
1.	Production (Manufacturing)	Modular, standardised, components	Abd Razak & Murray, 2022; Tuvayanond, 2023; Montazeri, 2024; Thajudeen, 2022
2.	Manufacturing	Off-site, factory – based precast production	He et al., 2021; Metvaei, 2025; Wasim et al., 2020; Gao et al., 2019
3.	Heavy Precast weight	Increased risk of accident during lifting and installation due to weight of large precast elements. Required specialised lifting equipment and skilled operators	Alawag et al., 2021; Abas & Arshad, 2021; Yusof & Kamal, 2024
4.	Swing wind	Wind induced swinging of heavy precast components during lifting poses significant safety hazard. Lack of detailed guidelines and risk mitigation strategies for wind conditions	Abas & Arshad, 2021; Yusof & Kamal, 2024

Source: Authors (2025)

IBS adoption in Malaysia is growing, but safety challenges in lifting and production especially those related to heavy precast components and swing wind remains insufficiently addressed in current research and industry practise. Despite increased IBS adoption in Malaysia, safety challenges in lifting and production processes remain underexplored. This study investigates safety-related optimisation challenges in IBS precast and lifting machinery based on stakeholder interviews in Malaysia

SAFETY CHALLENGES IN OPTIMISING IBS AND MACHINERY

Safety in IBS precast operations and lifting machinery is a critical concern, especially in rebars processing and concreting areas. Key risks include human error, machinery hazards, and site layout issues, with both IBS precast and lifting machinery presenting unique and overlapping safety challenges.

Table 7. Key Finding for Safety Challenges in the IBS Precast and Lifting Machinery for Area Processing.

No.	Area	IBS Precast Safety Challenges	Lifting Machinery Safety Challenges	Citations
1.	Rebars Processing Area	Rebars collision and uneven spacing Assembly errors Human errors and inadequate training	Low safety awareness Blind spots Human error in operation	Abd Razak & Murray, 2022; Tuvayanond, 2023; Montazeri, 2024; Thajudeen, 2022
2.	Concreting Processing Area	Component handling and storage Quality control Defect risk from mishandling	Load swing due to wind Over-rotation Collision with structures or workers	He et al., 2021; Metvaei, 2025; Wasim et al., 2020; Gao et al., 2019

3.	General	Increased risk of accident during lifting and installation due to weight of large precast elements. Required specialised lifting equipment and skilled operators	Alawag et al., 2021; Abas & Arshad, 2021; Yusof & Kamal, 2024
4.	Swing wind	Wind induced swinging of heavy precast components during lifting poses significant safety hazard. Lack of detailed guidelines and risk mitigation strategies for wind conditions	Abas & Arshad, 2021; Yusof & Kamal, 2024

Source: Authors (2025)

Both IBS precast and lifting machinery present significant safety challenges in rebars and concreting processing areas. Addressing these requires a combination of advanced technology, optimised site layout, systematic safety management, and enhanced worker training to minimise risks and improve overall safety.

Risk Assessment in the Rebar Production Area for Lifting Machinery

Safety at girders in IBS rebars processing areas is influenced by multiple hazards, especially when handling heavy loads, wind swing, and green concrete materials. The main risks stem from rebar corrosion, environmental degradation, and load handling, all of which can compromise structural integrity and worker safety.

Table 8. HIRARC for lifting Machinery at Rebars Production Area

No.	Hazard/ Challenges	Risk Assessments (Likelihood/Severity)	Risk Assessments (Likelihood/Severity)	Lifting Machinery Safety Challenges	Citations
1.	Wing swing with heavy loads	High/Medium	Win can destabilise suspended girders and rebars, increasing risk of collision or drop	Monitor wind, restrict lifts in high wind, secure loads, train operators	Jethwa, 2024
2.	Handling green (early-age) concrete	Medium/Medium	Green concrete is fragile, prone to cracking or failure during movement	Allow adequate curing, use proper lifting points, minimise handling	Lu et al., 2025
3.	Suspended load hazard	High/High	Workers exposed to falling loads during girder/rebar erection	Enforce exclusion zones, PPE, VR-based safety training for situational awareness.	Joshi et al., 2021; Jethwa, 2024
4.	Equipment failure (cranes, slings)	High/Low	Failure can cause catastrophic accidents with heavy precast elements	Regular Inspection, maintenance, operator certification	Jethwa, 2024
5.	Site congestion and logistics	Medium/Medium	Limited space increases collision and trip hazards	Plan site layout, clear pathways, stagger activities	Jethwa, 2024
6.	Inadequate safety training	Medium/High	Workers may not recognise or respond to dynamic risks	Implement VR and practical safety training	Joshi et al., 2021

Source: Authors (2025)

Risk Assessment in the Concreting Production Area for Lifting Machinery

In the IBS concreting processing area, especially at girder locations, significant safety challenges arise due to factors like wind swing, heavy loads, and the use of green (early-age) precast concrete. HIRARC (Hazard Identification, Risk Assessment, and Risk Control) frameworks are essential for systematically managing these risks.

Table 9. HIRARC for lifting Machinery at Concreting Production Area

No.	Hazard/Challenges	Risk Assessments (Likelihood/Severity)	Key Characteristics/ Factors	Risk Control Measures	Citations
1.	Wing swing with heavy loads	High/Medium	Win can destabilise suspended precast girders, especially during lifting/ placement	Use wind monitoring, restrict lifts in high wind, secure loads, train operators	Jethwa, 2024
2.	Handling green (early-age) concrete	Medium/Medium	Green concrete is more fragile, increasing risk of cracking or failure during movement	Allow adequate curing, use proper lifting points, minimise handling	Deng & Chen, 2023; Lu et al., 2025
3.	Suspended load hazard	High/High	Workers exposed to falling loads during girder erection	Enforce exclusion zones, PPE, VR-based safety training for situational awareness.	Joshi et al., 2021; Jethwa, 2024
4.	Equipment failure (cranes, slings)	High/Low	Failure can cause catastrophic accidents with heavy precast elements	Regular Inspection, maintenance, operator certification	Jethwa, 2024
5.	Site logistics and congestion	Medium/Medium	Limited space increases collision and trip hazards	Plan site layout, clear pathways, stagger activities	Jethwa, 2024
6.	Structural instability (girder)	High/Medium	Inadequate support or premature loading can cause collapse or excessive deflection	Temporary bracing, staged loading, monitor deflection	Lu et al., 2025; Deng & Chen, 2023

Source: Authors (2025)

Effective risk management at IBS girder locations requires a structured HIRARC approach, focusing on wind swing, heavy loads, green concrete fragility, and suspended load hazards. Controls include wind monitoring, exclusion zones, proper curing, equipment checks, and advanced safety training. These measures are critical for ensuring worker safety and structural integrity during IBS precast concreting operations. Significant safety challenges persist in Standard Operating Protocols (SOPs) and training for IBS precast and lifting machinery in Malaysia, Indonesia, and Brunei, especially when integrating dfMA principles. These gaps include outdated training methods, insufficient DfMA-specific SOPs, and limited risk mitigation strategies.

Table 10. Key Gaps in IBS Precast and Lifting Machinery for Safety Challenges SOPs & Training (DfMA context)

No.	Developing Countries	Key Gaps in IBS Precast and lifting Machinery for Safety SOPs & Training (DfMA Context)	Citations
1.	Malaysia	Incomplete hazard identification and risk mitigation in DfMA based IBS Project	Jamalluddin et al., 2024; Adnan, 2018; Abas & Arshad, 2021; Joshi et al., 2021

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		Limited integration of DfMA in safety SOPs Training often lacks DfMA specific contents and advanced methods (e.g Virtual Reality – VR) Psychological and procedural factors underemphasized.	
2.	Indonesia	New adoption of IBS and DfMA leads to high risk lifting operations SOPs and training not fully adopted to DfMA workflows Need for activity and based safety plans and operator certification Insufficient socialisation and evaluation of SOPs.	Saputra, 2022
3.	Brunei	No direct research found, likely faces similar gaps as Malaysia and Indonesia due to comparable industry maturity Lack of localised DfMA safety SOPs and training frameworks	No direct data

Source: Authors (2025)

Based on the aims and objectives, a research question has been developed such as How to determine the challenges in the Optimisation at IBS and lifting Machinery?

Therefore, from the aims and objectives research methodology of this paper was developed.

RESEARCH METHODOLOGY

This study used a qualitative research methodology, such as a semi-structured interview. Semi-structured interviews were chosen to gather in-depth information from leaders and experts in the IBS environment to identify challenges that emerge in IBS products and machinery, particularly those linked to safety. The process flow is described in Figure 2 below.

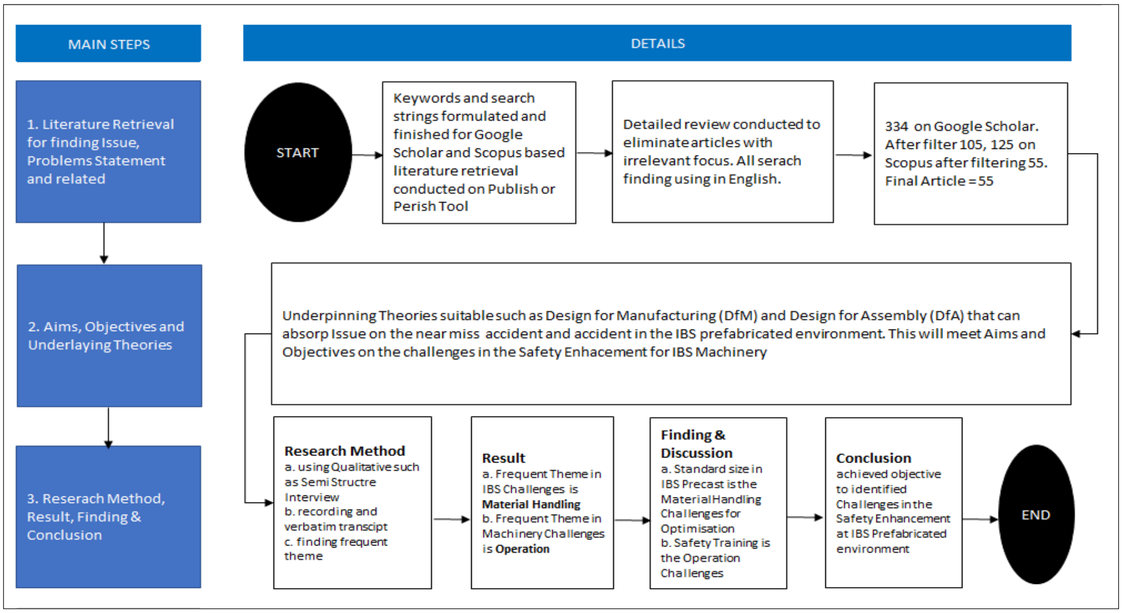

Fig. 2. Process Flow for This Study

Source: Authors (2025)

Based on this question, research methodology was developed starting from (1) a systematic literature review that focuses more on filtering best paper journals, (2) Sampling on the group and location of the study, (3) Using a protocol to collect data, (4) Recording interview conversation and verbatim, (5) Using snowball technique when interview, (6) Feedback Summary and Thematic Analysis. According to (Creswell & Thousand, 2007), to improve the preliminary survey of the interview guide, the primary question must be included, as well as the accompanying questions. Purposive and snowball sampling were used to conduct semi-structured interviews with eight IBS stakeholders in Selangor and Johor. The interview was conducted informally by reading the questions and asking about the respondent's background, experience, and years as a manager in the ranks that applied. Safety officers, production engineers, and plant managers participated. Table 11 below is used for this research, specifically for demographic information for the Interviewee.

Table 11. Demographic Information for Interviewee

No.	Interviewee Codes	Roles	Locations	IBS Plant Types	Years of Experiences
1.	INTS01	Plant Manager	Selangor	IBS Precast (Prefabricated)	More than 10
	INTS02	Production Engineer			More than 5
	INTS03	Safety Officer			More than 3
	INTS04	Technician			More than 15
2.	INTJ01	Plant Manager	Johor	IBS Precast (Prefabricated)	More than11
	INTJ02	Production Engineer			More than 8
	INTJ03	Safety Officer			More than 6
	INTJ04	Technician			More than 5

Source: Authors (2025)

Thematic analysis is a qualitative method used to identify, analyse, and report patterns (themes) within data. The interview was conducted with the respondent's agreement to capture data more effectively. For researchers, focusing on the interview material and vocal prompts is essential, as is the process of recording the interview, which will result in a "verbatim transcript" of the interview from the transcriptionist. To find recurring safety-related issues in material handling and lifting procedures, verbatim transcriptions of the data were analysed using theme coding. Below are the Table 12 for the steps in Thematic Analysis in the IBS Precast and Lifting Machinery.

Table 12. Steps in Thematic Analysis

No.	Steps	Descriptions	Application in IBS Precast/Lifting	Citations
1.	Data Collection	Gather qualitative data (e.g., interviews, site observations)	Interviews with workers, managers and site observations during precast and lifting operations.	Hamid, 2013; Abas & Arshad, 2021
2.	Transcription	Transcribe audio recordings or notes verbatim	Ensures accuracy and preserves the original context of safety incidents and practices	Hamid, 2013
3.	Initial Coding	Systematically code the data for meaningful units related to safety	Codes may include “unsafe worker behaviour,” equipment malfunction, lack of supervision	Yin, 2023; Hamid, 2013; Abas & Arshad, 2021

4.	Theme Identification	Group codes into broader themes representing recurrent safety challenges	Themes such as “human factors,” equipment risk,” “environmental hazards,” “Management issue”	Yin, 2023; Yong, 2023; Abas & Arshad, 2021
5.	Review and Refinements	Refine themes for clarity and relevance, ensuring they accurately reflect data	Cross-check with original transcripts and stakeholders feedback	Yin, 2023; Hamid, 2013
6.	Reporting	Present themes with supporting quotes or examples	Use tables, and direct quotes to illustrate key safety challenges	Yin, 2023; Hamid, 2013

Source: Authors (2025)

Data saturation is a key concept in qualitative research, marking the point at which no new themes or insights emerge from additional data collection. Saturation was reached after eight interviews as no new themes emerged. Below is the table 9 for data saturation process in snowball process for snowball sampling IBS Precast and lifting Machinery.

Table 13. Steps in Snowball process in Snowball sampling

No.	Steps	Descriptions	Application in IBS Precast/Lifting	Citations
1.	Initial Participants	Recruit initial interviewees with relevant experience in IBS precast and lifting machinery	Initial participants were selected on expertise in IBS precast operations	Hossain, 2024
2.	Snowball Sampling	Ask each participant to refer others with similar experience	Participants referred additional colleagues involved in lifting machinery	Hossain, 2024
3.	Data collection and Thematic Analysis	Conduct and transcribe interviews, coding for emerging safety themes	Interviews were analysed using inductive thematic analysis to identify safety challenges	Naem, 2024; Hossain, 2024
4.	Assessing saturation	Continue interviews until no new themes or codes emerge	Saturation was reached after 10 interviews as no new safety emerged	Guest et al., 2020; Hennink & Kaiser, 2021; Abas & Arshad, 2021; Naem, 2024; Hossain, 2024
5.	Stopping Data Collection	Cease recruitment and interviews once saturation is confirmed	Data collection stopped when further interviews yielded redundant information	Guest et al., 2020; Hennink & Kaiser, 2021; Abas & Arshad, 2021; Naem, 2024

Source: Authors (2025)

RESULTS

Result from the semi-structure interview were identified three themes such as Material Handling Hazard, Standardisation & Operation Capacity and lifting machinery safety gaps. Sixth quotes from the participants were identified inside Material Handling Hazard such as described in Figure 4. Four (4) quotes in the Material Handling Challenges mentioned shape, size, and weight that can impact the surroundings especially risks in terms of safety at workers at ground level and becoming waste if structure damage when lifting material using girder machinery.

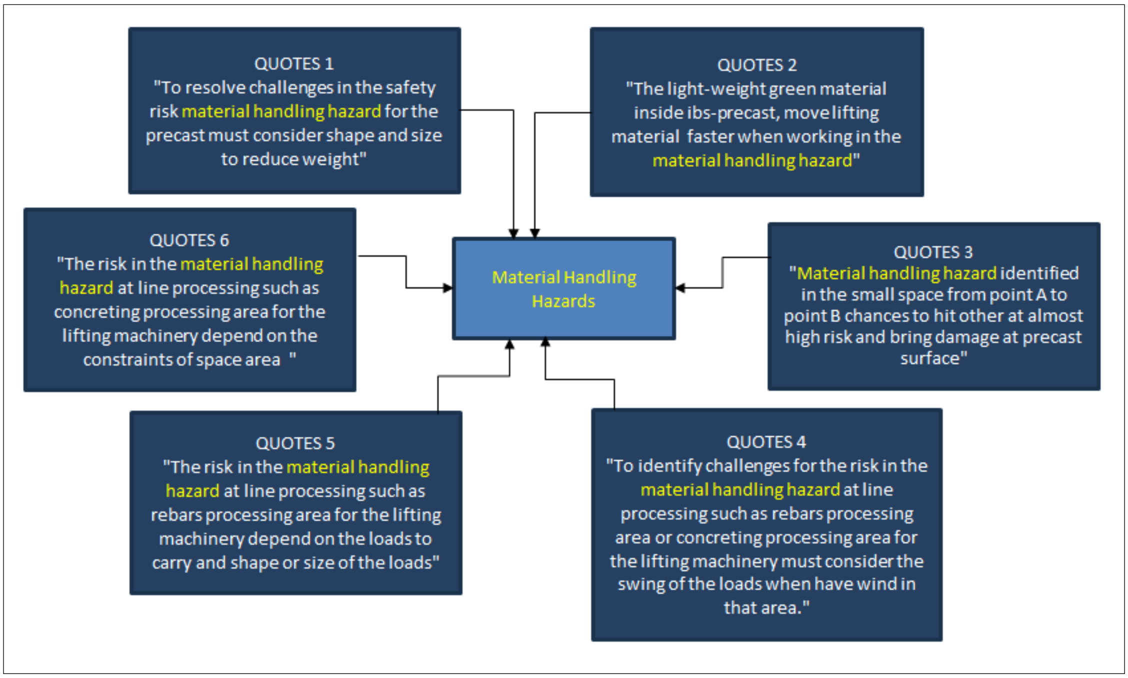

Fig. 3. Sixth Quotes for Material Handling Hazard Themes

Source: Authors (2025)

Quotes from Themes in The Material Handling Hazard

Quotes from Theme 1 stated that in our prefabricated plant, we have produced many sizes of precast walls, but the shape is still the same. We do not have any standard size; we almost produce what the customer needs. The bigger size normally needs more workers because it carries heavy loads and—(face looks worried)—more carefully to handle this situation, especially when handling material lifting.

"Normally to lift the IBS Product from point A to B make sure in good condition. Yes, agree that the size makes an impact on lifting IBS Products, especially for safety."

Normally, when lifting heavy IBS products, it takes more time compared to light IBS products. When the risk of falling down is higher, as mentioned by Theme 2:

"More time needs to be taken to make sure the lifted IBS product is in good condition without any damages and near-miss accidents. Ahhh.. Our concern is to avoid near-miss accidents, accidents, or damages when lifting IBS products. Checking the hook, the eye, and the test are the key elements before starting the procedure to lift the IBS Product. A person to make sure safety conditions at the site are safe must have the proper training for the ground people especially in safety handling material IBS products."

Quotes from Theme 3 described that before starting lifting from point A to point B, the route must check whether it has enough space to be lifted or not. The small space along the route makes it difficult to travel from point A to point B because this heavy IBS product will hit others and will cause damage, near-miss accidents, or accidents.

"Umm, still remember some situation that occurred when the heavy IBS product swung because got wind inside the route and hit because the space too small to lift. Ground people must check the space first before starting to move and lift the IBS Product. Yes agree, the small space when travelling and lifting IBS Products from point A to B impacts safety."

As an engineer in the processing line, the lightweight IBS Product is easier to handle compared to the heavyweight, as mentioned in Theme 4.

"The designer for the precast wall must consider reducing weight for us at the processing line handle material to lift and travel easily. Have 1 case, the heavyweight IBS product is not stable and swings. The engineer in this processing line got nervous when looking at this situation. The best practice, all ground people to make sure the hook, the eye, the fabric sling, or the chain is taken into consideration especially load calculation in appropriate SWL. Safety in the Material Handling in the line processing is the highest priority per each ground team."

Quotes from Theme 5 described that Ordinary Portland Cement (OPC) is used in ingredients such as chemicals and ash cement to make IBS Products. For the time being, no green material is adopted into ingredients to produce IBS Products in our prefabricated processing plant.

"Problem with Ordinary Portland Cement (OPC) easily hot temperature inside the house from 11:00 am till 04:30 pm and heavyweight. (The face shows in frowning). As a designer, we try to find the best material to make our IBS product that can be accepted by our users and easily for safety. Lightweight with green material is a challenge to find the best-suited IBS Product in terms of safety."

Size is the most important element when talking about high-capacity production. When the size is too big, the mass of the IBS product is not in the range of lightweight. This significantly reduces time processing and cost to prefabricated as mentioned by the interviewees in Theme 6. Material handling and operation in the line processing at the rebars production area and concreting production area are easier when it comes to lightweight because it moves and lifts faster compared to heavyweight.

"The technology of automation and robotics are also elements to capture speed and a safe environment because the rate of production manual using humans at a rate of 2.3 sqft/man-day. Erm, human error when working in the production area impacts the quality of the IBS product and near-miss accidents and accidents can occur in the production area."

In conclusion, factors such as size, weight, selection of material, and technology of machinery from manual replacing workers are the key elements for safety in material handling and operation.

Quotes from Themes in the Standardisation & Operation Capacity

Operation Challenges were identified from the semi-structured interview at participants' quotes as described in Fig. 5. Five (5) quotes in the Operation Challenges mentioned regarding lifting that can impact the surroundings, especially on the manual machinery, International and local code of practice, training handling lifting machinery and enhancement lifting machinery with IoT sensor to monitor wind blow when lifting material.

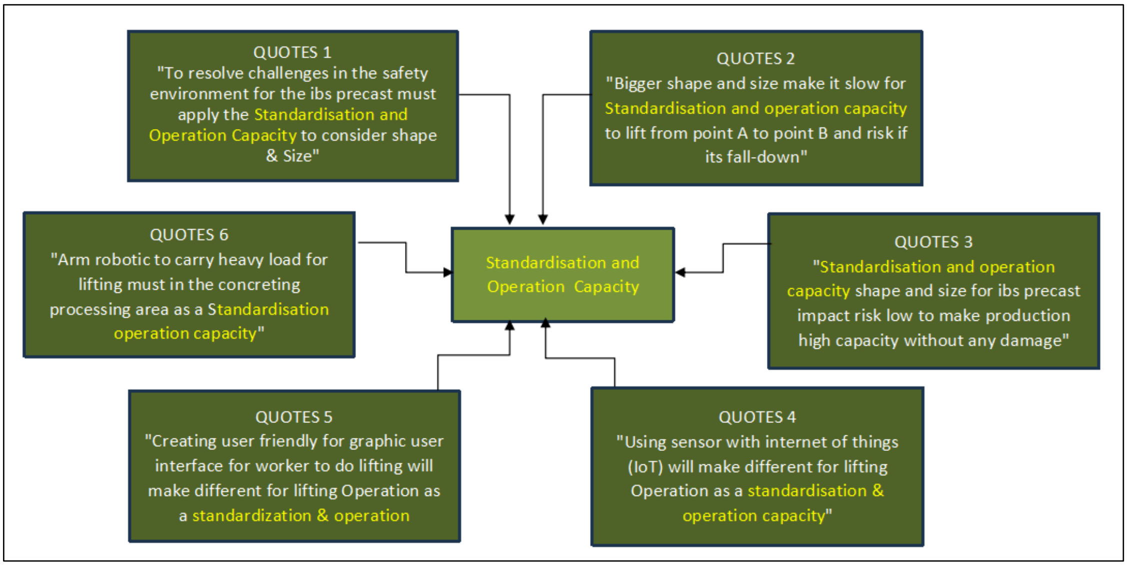

Fig. 4. Sixth Quotes for Theme Standardisation and Operation Capacity

Source: Authors (2025)

Quotes from Theme 1 stated that in our prefabricated plant, we have new semi-auto machinery, such as double girder lifting machinery, that can lift material that was previously manually transferred using a jib crane and trolley. This new machinery must be provided with a manual operating book.

"The supplier only gives us regarding drawing on the parts for double girder lifting machinery and brochure only. For the time being, we don't have any manual book guide or any framework for this operation using this double girder. This manual book or framework is useful for us, especially for safety purposes."

Before starting lifting using a double girder, we inspect hooks, eyes, fabric slings, or chains to ensure they are in good condition. For us, lifting heavyweight IBS products with this double girder is our priority for safety.

Normally, a Safety Operation Machinery Manual Book must be provided by the supplier when supplying double girder lifting machinery, as mentioned by the theme in Quotes 2. For the time being, the supplier does not include the Safety Operation Double Girder Lifting Machinery Manual Book.

The Safety Operation Double Girder Lifting Machinery Manual Book is important to guide personnel on the ground when operating the double girder lifting machinery. The Safety Site Supervisor must check that the double girder lifting machinery is in good condition and that the personnel in charge are well-trained to operate the machinery. A person in charge of safety has a priority to ensure conditions at the site are safe by checking that the person in charge has undergone training for the ground people, especially for the operation of safety lifting machinery.

Quotes from Theme 3 described ISO 45001 for Occupational Health and Safety Management used and applied in the IBS prefabricated plant. This ISO is concerned with Safety and Health. The company uses

ISO 45001 and has adopted it into company policy, but workers on the ground still have not fully applied it to their work. At the time, they do not have any framework that concerns IBS products and machinery.

"Erm, safety training must frequently be done for us to know and get knowledge. Ha, still remember, the near-miss accident that occurred last year when lifting an IBS product. Suddenly when moving and lifting, it swung from left to right and we decided to make a stop and tighten back all the sling at the eye. The most important thing is to check regularly the hook, eye, fabricated hook, or chain to make sure all are in good condition before starting to lift the IBS Product. The most important thing when doing the operation at processing lines such as rebars or concreting is to bear in mind that safety must come first."

Wind inside the prefabricated plant must be taken into the highest consideration because we do not know the location of the wind coming from on the rooftop, as mentioned by the theme in Quote 4. Wind inside the prefabricated plant can impact damage to the IBS product when swinging and touching others, which might fall and probably hit the ground workers. When this happens, such as damage to the IBS product, the capacity to produce becomes lower, and the time taken becomes longer to make new IBS products to replace the damaged ones that now become waste. All ground people must be alert and frequently alert for the sensor response if the prefabricated plant has this kind of technology to detect wind. Alertness for safety in a prefabricated IBS environment must be at the top of the priority list when ground people complete the operation task.

Quotes from Theme 5 described that bigger sizes are heavyweight while the smaller sizes are lightweight. Bigger sizes must have double safety and re-check all the conditions at the girder for lifting and IBS Products. The bigger size for the dimension of the IBS product can have a huge mass of tonnes.

"Be always careful. Be alert when completing the task. Damage, near-miss accidents, or accidents can occur if we do not focus on completing the job. Regularly do the maintenance for girder lifting machinery or other machinery. Audit the risk hazard in the production area. Identify the root cause if anything happens. The best attitude is to always check regularly and do the maintenance for safety."

Auditing is a key element of the operation in the production line for safety and to ensure a higher production rate.

Internet of Things (IoT), such as sensors, is nowadays important in day-to-day operations. The application of IoT can improve productivity and enhance safety in the IBS prefabricated plant, as mentioned by the theme in Quotes 6. IoT applications, such as sensors, can send data in real-time to the ground people using Bluetooth technology on their handphones to make them alert to any situation needing fast action.

"When our company sends technical people to learn technology in Germany for this IoT, we learn this type of technology that is applied in car manufacturing can improve more on the work conditions and benefit the company in the long run. The most important thing is our workers must learn and adopt this new IoT technology. Our workers' attitude must take the mind challenges for use and applied in our IBS prefabricated environment."

Attitude is most important for every worker to support the company's transformation from manual operation into an automated environment, especially for safety purposes.

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Quotes from Themes in the Lifting Machinery Safety Gaps

Operation Challenges were identified from the semi-structured interview at participants' quotes as described in Fig. 6. Five (5) quotes in the Operation Challenges mentioned regarding lifting that can impact the surroundings, especially on the manual machinery, International and local code of practice, training handling lifting machinery and enhancement lifting machinery with IoT sensor to monitor wind blow when lifting material.

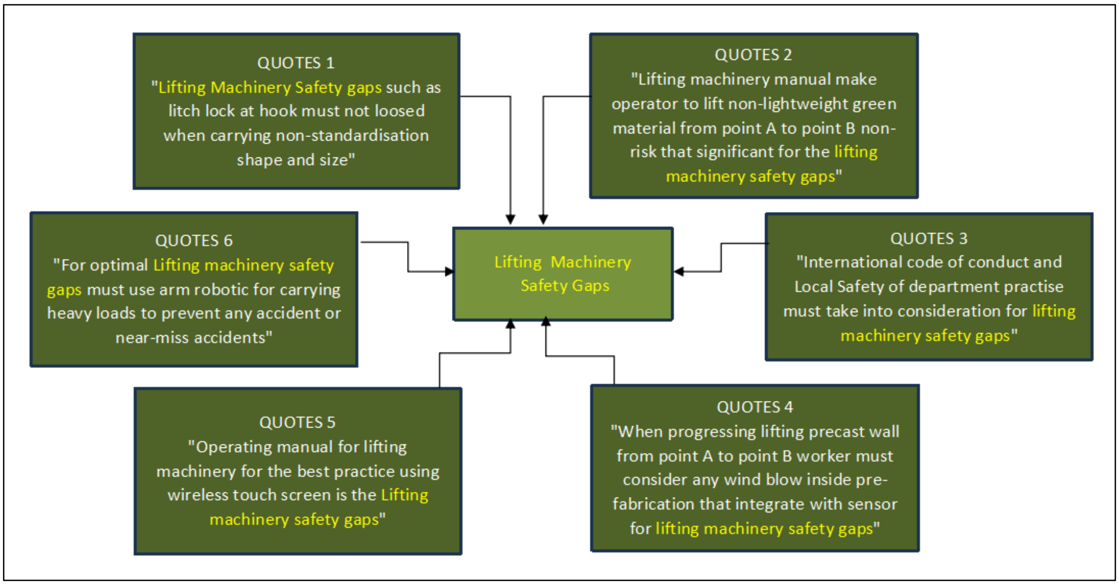

Fig. 5. Sixth Quotes for Theme Lifting Machinery Safety Gaps

Source: Authors (2025)

Quotes from Theme 1 mentioned lifting machinery safety gaps, specifically that the safety latch at the hook must not loosen when carrying non-standardised shapes and sizes.

"Normally, the latch lock may loosen when carrying irregular shapes or sizes. Lack of inspection of lifting accessories will impact load slippage, dropped loads, severe injury, or fatality risk, especially with complex or unpredictable loads, as mentioned by the safety person."

Quotes from Theme 2 highlighted that traditional IBS precast without using green material is usually heavy when manually lifted. Standard risks remain, such as strain from improper lifting, and there is less risk reduction compared to material innovation, such as the adoption of green materials. There is also a persistent risk of musculoskeletal injury, equipment failure, and accidents if the protocols are weak.

Quotes from Theme 3 mentioned the International Code of Conduct and local safety department practices regarding lifting machinery safety gaps. This involves the integration of global codes and local practices, such as ISO 45001 for Occupational Health and Safety Management, which is used and applied in the IBS prefabricated plant. This ISO is concerned with Safety and Health.

"The company uses ISO 45001 and has adopted it into company policy, but workers on the ground still have not applied it to their work. At the time, there was no framework that concerned IBS products and machinery. Erm, safety training must frequently be done for us to know and gain knowledge."

The findings identified gaps in technical standards, inconsistent safety inspections, lack of emergency response, and insufficient training. The risk implications include non-compliance, outdated practices, and inadequate adaptation to site-specific hazards.

Quotes from Theme 4 discussed integrating a wind sensor with IoT to address lifting machinery safety gaps. The gaps identified include sensor deployment, data integration, and automated response.

"Our machinery uses semi-automation that is not integrated with a wind sensor and the Internet of Things (IoT). Both technologies can enhance risk detection and prevention. Still remember a near-miss accident that occurred in our concreting production area when lifting a heavy IBS precast. Suddenly, the precast wall swung wildly without any alarm and nearly crashed into workers in that area."

Quotes from Theme 5 mentioned that wireless touchscreens enable remote, mobile operation with visual feedback, which is considered for lifting machinery safety gaps. The main safety gaps include interface reliability, latency, distraction, and insufficient auxiliary alarms with robust safety protocols.

"Normally, ground workers, such as operators, control the movement using pendant controls that do not integrate with the sensor. The situation is still fresh in memory when ground personnel are not well-trained in using the pendant control, making the movement of the lifting machinery out of control."

Quotes from Theme 6 focused on the Robotic Arm for optimal safety in lifting machinery. Gaps in adaptive control, workspace optimisation, and real-time hazard detection were described as the main gaps inside robotic arms. Normally, robotic arms replace manual lifting to prevent accidents, offering a significant reduction in accidents and near-misses, but they are dependent on advanced control and monitoring.

"A big precast wall (fear face) poses significant personnel risk if anything happens when falling after lifting the precast. The best option is to apply a robotic arm in the processing area."

FINDINGS & DISCUSSION

A robust safety culture in construction depends on clear procedures, effective training, and standardised practices. The following tables summarise the key implications of (1) missing SOPs/manual operations and near-miss incidents, (2) training gaps despite automation, and (3) the need for standardised precast sizes to reduce lifting risk.

Finding for implication Missing SOPs, Manual Operation, and Near-Miss Incident

Table 14. Finding Missing SOPs, Poor Supervision and Near-miss

No.	Issues	Implications	Citations
1	Lack of SOPs/ manual operation	Increased uncertainty, higher risk of incidents, inefficiency in operations	Al Shuaaili & Eneizan, 2023; Hashmi, 2024; Duan & Li, 2022

2	Underreporting of near-misses	Hinders proactive safety management and learning from incidents	Hashmi, 2024; Duan & Li, 2022; Duryan et al., 2020
3	Poor supervision/training	Major root-cause of near – miss incidents and safety system failure	Al Shuaaili & Eneizan, 2023; Hashmi, 2024

Source: Authors (2025)

Training Gaps Despite Automation

Table 15. Finding Implication for Training Gaps Despite Automation

No.	Issues	Implications	Citations
1.	Insufficient Training	Workers unprepared for new technologies, increased risk of errors / accidents	Azuarule, 2025; Adami & Teizer, 2021; Hussain, 2024; Kim, 2025
2.	Language/literacy barriers	Reduce training effectiveness, especially for migrant workers	Hussain, 2024; Demirkesen et al., 2015
3.	Traditional methods outdated	VR/AI-based training improves knowledge and safety behaviour over old methods	Adami & Teizer, 2021; Hashmi, 2024; Hussain, 2024; Jelani & Ali, 2020; Albert & Hallowell, 2021

Source: Authors (2025)

Need for Standardisation Precast Sizes to Reduce Lifting Risk

Table 16. Finding Implication for Non-standardised Precast

No.	Issues	Implications	Citations
1.	Non-standardised precast	Increased lifting risk, inefficiency, frequent readjustments, higher injury	Antoniou, 2020; Zou et al., 2022; Tan, 2024
2.	Standardisation	Improves safety, reduces complexity, enhance efficiency and procurement	Antoniou, 2020; Lao, 2023; Tan, 2024
3.	Lack of guidelines	Manufacturers hesitant to invest, perpetuating risk and efficiency	Antoniou, 2020; Lao, 2023

Source: Authors (2025)

CONCLUSION AND FUTURE RECOMMENDATIONS

Implementing standardised SOPs, increasing automation, and conducting regular safety audits with ISO-based training are essential strategies for improving safety and efficiency in IBS precast production, particularly in rebars and concreting areas are some for recommendation.

Optimising safety in lifting operations at IBS precast facilities requires integrating DfMA principles. DfMA emphasises early-stage design coordination, process simplification, and leveraging digital tools to enhance both safety and efficiency in the rebars and concreting production areas.

Table 17. Future recommendation SOPs Components for Lifting

No.	SOP Components (DfMA - Aligned)	IBS Precast Contributions	Citations
1.	DfMA - Driven Audit Planning	Design audit checklist to address DfMA - specific risk (e.g handling, assembly, and transport)	Kim & Kim, 2022; Anvari et al., 2025
2.	Continuous Hazard Monitoring	Use real-time monitoring of worker access to hazardous areas and proximity to dynamics risks	Kim & Kim, 2022; Shu, 2023; Zhao et al., 2022
3.	Digital & Automated Quality Checks	Employment automated and digital tools for dimensional and process quality assessment	Shu, 2023; Zhao et al., 2022
4.	ISO-Based Training Implementation	Deliver regular, standardisation training aligned with ISO and DfMA including PPE, equipment, and process safety	Joshi et al., 2021; Kim & Kim, 2022
5.	Innovative Training Methods	Integrate VR-based modules for immersive, scenario – based safety trainining	Joshi et al., 2021
6.	Continuous Feedback & SOP Updates	Use audit and Training outcomes to continuously refine SOP's and addressed emerging tools	Kim & Kim, 2022; Joshi et al., 2021

Source: Authors (2025)

A standardised SOP for lifting operations in IBS precast rebars and concreting areas, grounded in DfMA, should integrate early design planning, digital layout optimisation, automation, and ergonomic safety. Leveraging BIM4D, computer vision, and VR-based training ensures safer, more efficient lifting processes, while continuous feedback supports ongoing improvement.

Integrating automation and sensor technologies in IBS precast rebars and concreting areas—guided by DfMA principles—can significantly enhance safety, efficiency, and quality. A standardised SOP ensures these technologies are implemented systematically and safely.

A standardised SOP for optimising safety in automation and sensor integration at IBS precast facilities should embed DfMA principles from the design stage, leverage robotics and real-time monitoring, and ensure ongoing staff training. Continuous feedback and digital integration further support a safer, more efficient production environment in both rebars and concreting areas

Table 18. Future Recommendation SOPs Components for Training Gaps Despite Automation

No.	SOP Components (DfMA - Aligned)	Key Action Guidelines	Citations
1.	Early Design Integration	Incorporate automation and sensor need into components and process design to minimise manual handling and risks	Wasim et al., 2020; Li, 2024
2.	Automated Sensor deployment	Use robotics for precise, repeatable sensor placement, reducing human	Tshibombo, 2025; Zhao et al., 2022
3.	Real – Time Monitoring & Control	Implement sensor networks and real-time data analytics for continuous safety monitoring and predictive maintenance	Zhang et al., 2017; Sharma, 2024

4.	Safety Training & Protocols	Provide targeted safety training (including VR Modukes) for staff interacting with automated systems and sensor	Joshi et al., 2021
5.	Continous Feedback & SOP Updates	Regularly data and incidents reports to update SOPs and address emerging risks	Wasim et al., 2020; Zhang et al., 2017; Sharma, 2024

Source: Authors (2025)

Conducting effective safety audits and ISO-based training is critical for risk reduction in IBS precast rebars and concreting areas. Integrating DfMA principles ensures these processes are systematic, proactive, and tailored to the unique challenges of precast production.

A standardised SOP for safety audits and ISO-based training in IBS precast rebars and concreting areas should leverage DfMA principles, real-time monitoring, digital quality checks, and innovative training methods like VR. Continuous feedback and alignment with ISO standards ensure ongoing safety optimisation and risk reduction

As a conclusion of this study, we were able to identify challenges in the safety of IBS and machinery through semi-structured interviews with IBS prefabricated Malaysia stakeholders. This challenge is suitable for adopting underpinning theory for building a framework that focusing in Audit and ISO Based Training, Training gaps despite automation and lifting.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Muhamad Yusof Abdullah conceptualised the research idea, designed the methodology, conducted the investigation, collected and analysed the data, and drafted the manuscript. Ani Saifuza Abdul Shukor supervised the research and provided guidance throughout the article's revision process. Rohana Mahbub contributed to the critical review, commentary, and refinement of the manuscript.

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