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Workplace accident risk analysis using the bowtie method in the construction industry: a literature review

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ABSTRACT
Occupational Health and Safety (OHS) is an important aspect of decent work, with work accident statistics assessing worker protection from hazards and risks. The construction industry, which has a high risk of accidents, requires effective risk management, including bowtie analysis. The purpose of this study is to determine how to use the bow tie technique to examine work accidents in Indonesia's construction industry. A systematic review with a PRISMA approach was conducted. Relevant articles were searched during the period 2018-2023 through Sinta, Google Scholar, and PubMed using predefined inclusion and exclusion criteria, namely "bowtie method" and "Bow tie Analysis in Indonesia." Out of 18 articles identified with the specified keywords, quality evaluation resulted in six selected articles that met the criteria. The research findings encompass various risks such as the collapse of girder beams and accidents related to COVID-19. The impacts involve various levels of injuries up to fatalities, with mitigation efforts including the use of Personal Protective Equipment (PPE) and operator supervision. Analysis of the findings through tables and diagrams presents consistently emerging common risks. Detailed findings on the highest risks, namely girder collapse and workers falling from heights, provide a comprehensive overview of threats, consequences, and mitigation efforts.

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INTRODUCTION

Occupational health and safety is a crucial aspect in creating suitable working conditions. Within this framework, workplace accident statistics play a central role as the primary basis for assessing the level of protection of workers from potential hazards and risks associated with their jobs. This statistical data is key to ensuring the creation of a safe and protected work environment (ILO, 2023).

In 2016, diseases and injuries resulting from the work environment accounted for 1.9 million deaths (WHO, 2021). Non-communicable diseases contributed to 81% of the total deaths, with chronic obstructive pulmonary disease (450,000), stroke (400,000), and ischemic heart disease (350,000) being the leading causes. Meanwhile, work-related injuries accounted for 19% of the total deaths (360,000) (WHO, 2021). Studies considered 19 risk factors, such as long working hours, exposure to air pollution, asthma, carcinogens,

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ergonomic risks, and workplace noise. The main risks were long working hours (750,000 deaths), while exposure to air pollution in the workplace caused 450,000 deaths (WHO, 2021).

Certain industries, such as the construction industry, have high risks of workplace accidents. Hazardous working conditions and high risks emerge due to the distinctive and dynamic nature of the construction industry. Specifically, the construction sector is considered the riskiest compared to other industries, due to its dependence on labor as the primary resource (Fitri & Budiyanto, 2023). Workplace injuries can arise from physical, biological, chemical, or psychosocial hazards. Despite prevention efforts being implemented, injuries still occur frequently due to factors such as poor ergonomics, manual handling of heavy loads, and lack of safety training (Varacallo & Knoblauch, 2023). In efforts to prevent workplace accidents, actions involving job, supervision, and training are imperative. One effective approach is through workplace accident risk analysis (Boariu & Armean, 2020). By conducting this analysis, employers can identify potential hazards, take steps to eliminate or control them, and ultimately reduce the risk of workplace accidents (Prabaswari et al., 2020).

In the context of workplace accident risk analysis, the bowtie method can be used to assess the risks of accidents and injuries in various industries, such as the chemical industry. Lean principles and fuzzy bowtie analysis can be integrated for a more holistic risk assessment (Poleto et al., 2021). The Bowtie methodology involves several steps, including hazard identification, threat assessment, consequence assessment, risk control, and progress recovery (Fahmi et al., 2023). The advantage of the bowtie method lies in its graphical representation, which facilitates the visualization of the relationship between hazards, threats, and consequences. This helps stakeholders to better understand and communicate the associated risks (McLeod & Bowie, 2018).

Although there are several methods of workplace accident risk analysis available, the bowtie method stands out for its clear presentation through graphical representation. Unfortunately, in Indonesia, the application of the bowtie method in risk analysis is still limited and not common in various industries, including the construction industry. Therefore, the issue that becomes the focus of research in this study is how the bowtie method is used in the context of workplace accident risk analysis in the construction industry?

METHODS

Strategy

The PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) approach was utilized in this systematic review to investigate papers published between 2018 and 2023 related to the analysis of workplace accident risks using the bowtie method. Several search engines were used to find articles. The keywords “metode bowtie” and “Bow tie Analysis in Indonesia” were first used on the Sinta Source Journal website (https://sinta.kemdikbud.go.id/journals),thenon Google Scholar (https://scholar.google.com/), and finally on PubMed (https://pubmed.ncbi.nlm.nih.gov/).

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On the SINTA site, the search was conducted by entering the keyword "public health," resulting in 35 journals from SINTA categories 2-5. Next, a search with the keyword "engineering journal" yielded 115 records from SINTA categories 2-6. Subsequently, articles in each journal were searched using the predefined keywords. Meanwhile, on Google Scholar and PubMed sites, article searches were conducted by directly entering the predetermined keywords. The article review process can be seen in Figure 1 to provide a visual overview of the steps taken in this research.

Eligibility Criteria

In the article selection process, the inclusion criteria applied include: (1) studies specifically analyzing workplace accident risks with the bowtie method, (2) the location or research site being in the construction field in Indonesia, (3) journal articles indexed in reputable indexing agencies such as SINTA, Copernicus, or Scopus, (4) written in Indonesian or English, and (5) journals published between 2018 and 2023. As a contrast, exclusion criteria explicitly include: (1) articles inaccessible in full-text and (2) articles published in Proceedings Journals.

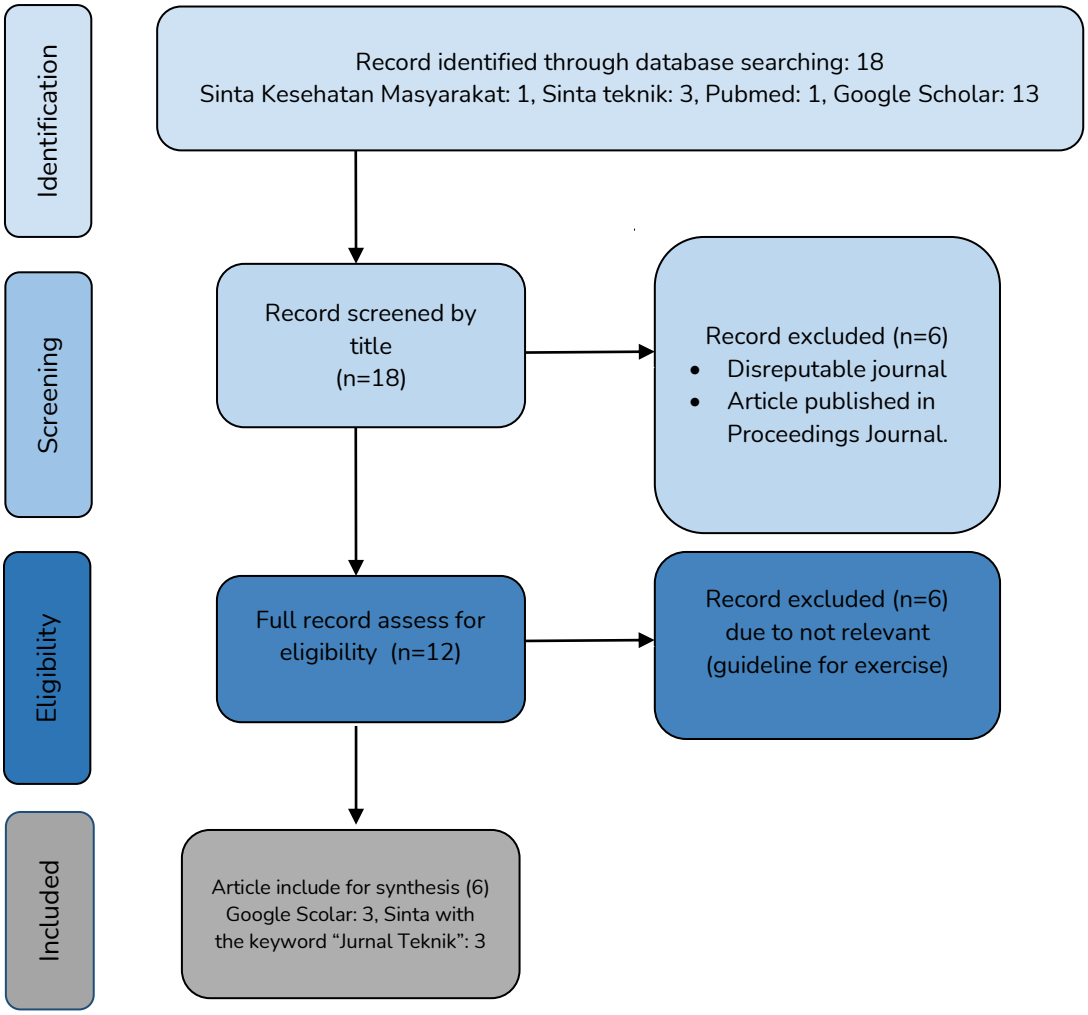

Figure 1. Screening Flowchart

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Table 1. Risk Analysis of Workplace Accidents Using the Bowtie Method

No	Name (Year))	Title	Method	Result
1	Maddeppungeng, Asyiah, & Iqbal (2021)	Metode *Bowtie* Untuk Dampak Kecelakaan Kerja Pada Proyek Jalan (Studi Kasus Proyek Pembangunan Jalan Tol Serpong – Balaraja Seksi I A)	The Bowtie Method was used in this accident investigation, and the analysis data used were derived from the results of questionnaires given to personnel in the previously designated division.	Several potential workplace accidents can occur during implementation; these hazards include 19 categories of Low, 31 categories of Medium, and 1 category of High, which is the collapse of girder beams and workers being crushed (7b). The final part of this study further indicates that the causes of workplace accidents include operator/staff errors, natural/environmental variables, as well as machine and material issues. Workers experience severe injuries/deaths, heavy equipment is destroyed, losses occur due to damaged materials, and losses occur due to time delays.
2	Alfarezi, Soetjipto, & Arifin (2021)	Analisis Risiko Keselamatan Dan Kesehatan Kerja (K3) Pada Masa Pandemi Covid-19 Dengan Metode *Bowtie* Analysis	Bowtie Analysis was utilized in this study because it not only identifies risks but also maximizes the mitigation of key variables and their impacts.	There are five prominent hazards stemming from 20 causal factors, with 14 influencing the likelihood of workplace accidents. Damaged crane slings, overturned cranes, workers falling while constructing scaffolding, workers falling while painting, and workers falling from lifts are some of the most common threats. Meanwhile, hazards associated with the COVID-19 pandemic have a minor impact on the main risks of workplace accidents. The risk response in this study includes 36 mitigation options to prevent and manage these hazards.
3	Bramantio & Rachmawati (2021)	Analisis Risiko Kecelakaan Kerja Menggunakan Metode *Bowtie* pada Proyek *The Grandstand*	This research utilized the AS/NZ 4360:1999 Risk Management standard to identify risks through	The most prominent workplace accident risks involve excavators falling due to muddy or slippery ground conditions, and workers falling from heights while

		Surabaya	preliminary and main survey questionnaires. Risk assessment based on the main survey was conducted by calculating likelihood and severity, forming a risk analysis matrix to identify key workplace accident risks. Subsequently, these risks were analyzed for their causes, impacts, and controls using the bowtie analysis method.	working with column formwork. Bowtie analysis indicates that the primary causes of these risks are negligence or lack of focus from workers, with the impacts being excavators falling into holes and workers falling from heights. Potential mitigation for these risks includes the use of Personal Protective Equipment (PPE) and fall restraint systems.
4	Pramesti & Rachmawati (2023)	Analisis Risiko Kecelakaan Kerja pada Proyek Pembangunan Jalan Tol Yogyakarta–Bawen Paket 1 (Seksi 1) Menggunakan Metode *Bowtie*	Through preliminary and comprehensive surveys, this research identified hazards related to workplace accidents. In the initial step, significant hazards were identified by calculating severity and probability indexes, which were then analyzed using Bowtie Analysis.	Three extreme risks were identified: the toppling of girder segments, crane sling falling/snapping while lifting girders, and girder collapse. Subsequently, a risk analysis was conducted using the bowtie method to determine the causes of operator incompetence, worker fatigue, sudden weather changes, aging heavy equipment, excessive loads, minimal safety signage, non-compliant maneuvers, and imperfect girder installation. The impacts of these risks could result in worker injuries where control measures such as the use of Personal Protective Equipment (PPE) and heavy equipment damage where escalation factors could include the enforcement of PPE usage and equipment suitability inspections.
5	Dhuha & Wiguna (2023)	Analisis Risiko Proyek Pembangunan Relokasi Jalan Nasional Mempawah-Sungai	Data were collected through the use of questionnaires, focused group discussions, and interviews.	There are six top risks, including site conditions and data not aligning with plans, design modifications during the project, land not being cleared for work, inclement

		Duri Kalimantan Barat	Subsequently, quantitative analysis was conducted using response scenarios and Bowtie Analysis.	weather, cost overruns, and material price increases. The emergency costs amount to Rp15,757,472,740 or 8.34% of the project value of Rp188,909,724,300.
6	Bhayangkara, Setyawan, & Handayani (2023)	Analisis Kecelakaan Kerja Pada Struktur Bawah Blending Silo Proyek "EPC Talavera" Tuban Menggunakan Metode *Bowtie*	The Bowtie Analysis method is used to assess the causes, effects, and responses to workplace accident risks.	The top workplace accident risks include being impaled by sharp objects, fingers getting caught in machinery, and electric shocks. Scattered sharp equipment, worker distraction, inappropriate equipment, poor machine conditions, and improper operation methods are the main causes. Additionally, damaged welding seams, extreme weather, and electrical current leakage in welding equipment are also concerns. The impacts include minor injuries, severe injuries/death, fires, and equipment damage. The bowtie approach is employed to investigate risk responses and risk controls for significant hazards, including escalation factors and escalation controls.

Review Process

In conducting database searches, specific search tactics were employed using the keywords "bowtie method" combined with "Bow tie Analysis in Indonesia" in the titles and abstracts of articles. Duplicate articles were identified and removed from consideration. Next, inclusion and exclusion criteria were used to filter articles. A list of titles from all articles found in the database was compiled. Subsequently, evaluation of the selected research list was performed to determine the most relevant studies, while irrelevant publications were eliminated. In this process, Mendeley software was used for evaluation, title compilation, abstract compilation, duplicate article detection, and removal of articles that did not meet the predetermined criteria. This approach ensures that relevant and high-quality research is retained while removing duplicates and irrelevant content.

Quality Assessment

After downloading and extracting articles into a specific database, the articles were evaluated according to inclusion criteria and guidelines. Articles that did not meet quality reporting requirements were excluded.

Ekstraksi Data

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Six articles were selected after quality assessment. These articles were presented in tabular form, including author names, year of publication, research title, research design, research findings, journal ranking, and article links. These results can be seen in Table 1. Furthermore, an analysis of frequently occurring workplace accident risk incidents in each study was conducted, which can be seen in Table 2. Subsequently, a bowtie analysis based on frequently occurring workplace accident risks was conducted.

RESULTS AND DISCUSSION

Result

Based on the research findings in Table 1, several workplace accident risks tend to occur frequently or have similarities across multiple studies. Here are some risks that can be identified as common or frequent, as seen in Table 2.

Table 2. Common Workplace Accident Risks in Construction Research

No.	Risk	Related Studies	Risk Analysis
1	Collapse or Falling of Girder Beams	Studies 1 and 4	High and Extreme (as per analysis in the articles)
2	Worker Falls	Penelitian 2 dan 3	High and Extreme (as per analysis in the articles)

Based on Table 2, it is known that the workplace accident risks in this study involve workers falling and the collapse or falling of girder beams. Therefore, a risk analysis of workplace accidents is conducted using the bowtie method created based on these two risks. The bowtie analysis can be found in Figures 2 and 3.

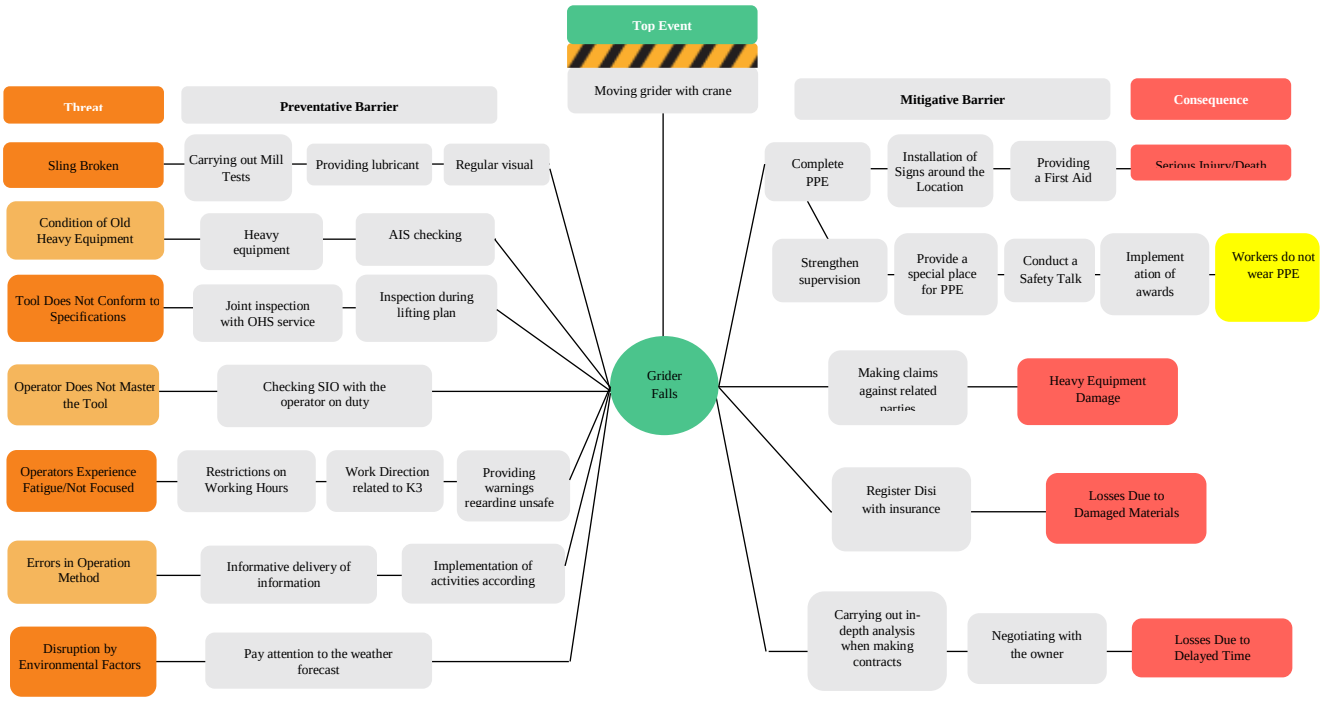

Figure 2. Bowtie Analysis of Girder Beam Collapse or Falling Risk
Source: Maddeppungeng et al. (2021) and Pramesti & Rachmawati (2023)

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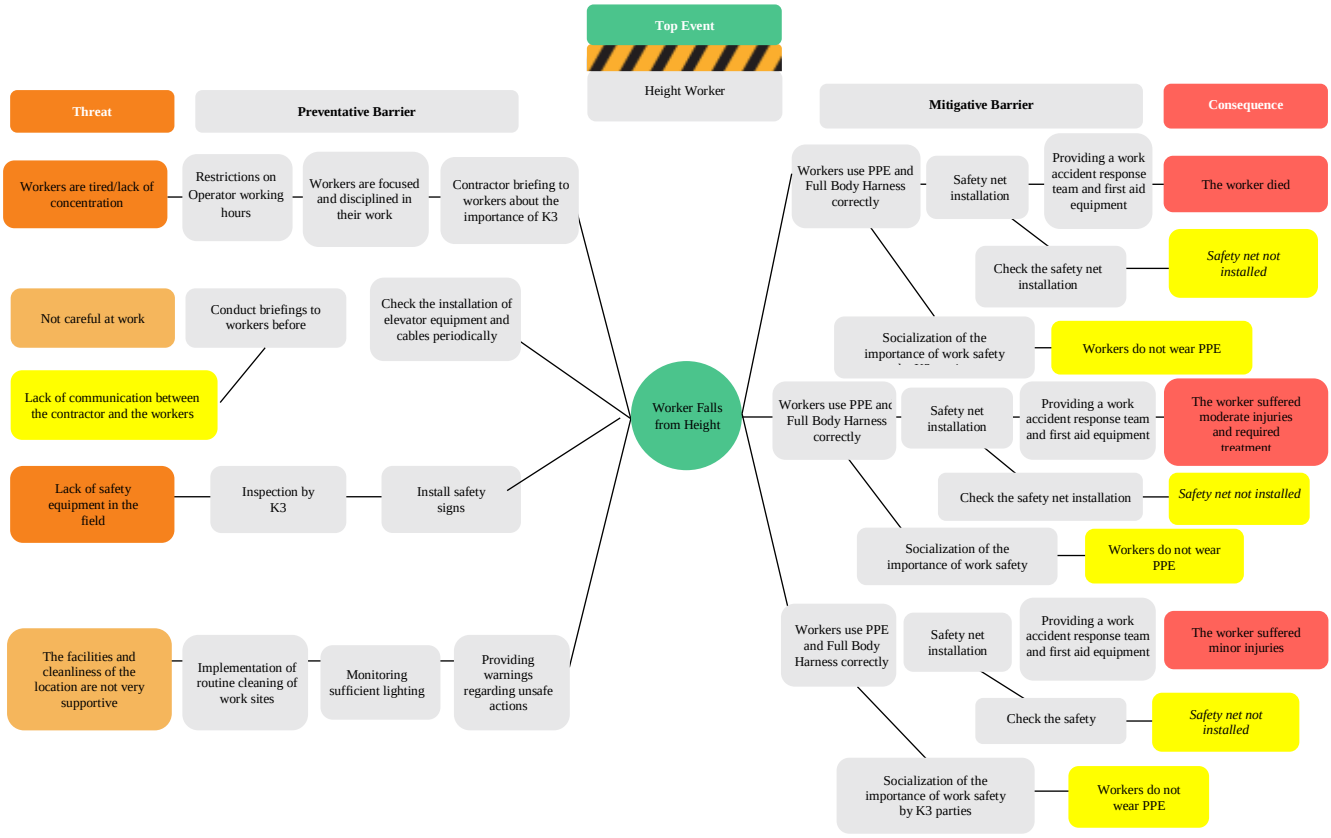

Figure 3. Bowtie Analysis of Workers Falling from Heights Risk
Source **:** Alfarezi at al. (2021) and Bramantio & Rachmawati (2021)

Based on Figures 2 and 3, it is found that the highest risk of work accidents in the construction field is related to collapsed or falling girders and workers falling from heights. Threats related to collapsed or falling girders include broken slings, aged heavy equipment, equipment not meeting specifications, operators not proficient with the equipment, operator fatigue/distraction, errors in operating methods, and environmental factors. The potential consequences include severe injuries/death, damage to heavy equipment, losses due to damaged materials, and delays. Meanwhile, threats concerning workers falling from heights consist of worker fatigue/lack of concentration, lack of caution in work, insufficient safety equipment on site, and inadequate facilities and cleanliness at the location. Potential consequences include worker fatalities, workers sustaining moderate injuries requiring treatment, and workers sustaining minor injuries.

Discussion

The construction industry poses higher risks of workplace accidents compared to other sectors, with accident rates and incidents on construction sites being the highest when compared to other workplaces (Abukhashabah et al., 2020). herefore, the analysis of workplace accident risks becomes an integral part of risk management in the construction industry. In managing risks, employers need to carefully identify and assess potential

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hazards. Thus, they can make effective decisions regarding resource allocation and implement appropriate strategies to minimize accident risks (Alkaissy et al., 2022).

One effective method for risk management in the construction industry is the Bowtie Method. This method is a barrier-based risk management tool that uses diagrams to graphically illustrate and communicate the interaction of various factors leading to specific hazards. By utilizing the Bowtie Method, potential hazards can be identified, related risk analysis can be conducted, and strategies can be developed to mitigate these risks (Rayner et al., 2020). The Bowtie analysis method considers barriers that can prevent accidents, such as safety measures, training, and equipment design (McLeod & Bowie, 2018). Bowtie analysis can be adapted to incorporate human factors and cognitive aspects, such as perception, memory, and reasoning, to assess accident risks in complex work environments like offshore platforms (Moreira et al., 2023).

Assessment of confined space risks: Bowtie Analysis can be used to assess accident risks in confined spaces during construction projects, such as waste processing installations, by referring to established safety requirements and conducting focused group discussions to develop graphical frameworks to prevent confined space accidents (Amin & Mohammad, 2023). Risk assessment of mooring chain replacement: Bowtie Analysis can be applied to analyze risks associated with mooring chain replacement on offshore production barges, identifying potential hazards and risks that can impact safety, economics, and the environment (Bramantio & Rachmawati, 2021).

The Butterfly Diagram Method uses simple cause-and-effect scenarios with barriers to communicate risks to the audience (de Ruijter & Guldenmund, 2016). The Butterfly Diagram Method is a proactive approach to risk management because it focuses on identifying and mitigating potential hazards before they occur (Abdi et al., 2016). The Bowtie method is preferred over other accident risk analysis methods for several reasons. It provides a simple visual explanation of a risk that would be much more difficult to explain, giving an overview of several plausible scenarios in one image (Wolters Kluwer, 2023a). It also identifies control measures and failure modes, as well as control measures that may be taken for these failure factors (Wolters Kluwer, 2023b). Additionally, the butterfly model is popular because it represents the entire accident scenario, including causes and effects (Khakzad et al., 2012).

CONCLUSION

Research related to the analysis of workplace accident risks in the construction industry and other sectors using the bowtie method is still limited. From the review of six articles, it was revealed that the highest and most frequent risks in the construction sector are falling girders and workers falling from heights. The highest risks in construction encompass two main aspects: collapsed or falling girders and workers falling from heights. Threats to girders involve the potential for broken slings, the use of aged heavy equipment, and operator lack of focus. The consequences involve severe injuries up to the risk of death. Meanwhile, threats to falling workers involve factors such as fatigue and inadequate use of safety equipment. The consequences can vary from minor injuries to potentially fatal ones.

To enhance understanding and implementation of preventive measures for workplace accident risks, especially in the construction sector, it is recommended to increase research using the bowtie method. The primary focus of this research should be on identifying and mitigating key risks, particularly those related to falling girders and workers falling from heights. Operational aspects and supervision need special attention to ensure the effectiveness of preventive measures. The implementation of directly measurable prevention measures, such as intensive training, routine equipment maintenance, and increased use of safety equipment, is expected to significantly improve workplace safety levels in construction fields.

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