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Analysis of Factors Causing Occupational Accident Risks Using the HIRARC and Bowtie Analysis Method in the Mall Building Construction Project in Bekasi

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Abstract

Construction work is associated with high occupational safety and health risks, especially in building construction projects. This study aims to identify the causes of occupational accidents in the Bekasi Mall Construction Project by using Hazard Identification, Risk Assessment and Risk Control (HIRARC) and Bowtie Analysis. Data collection was by means of field observations, interviews and questionnaires. The level of risk was determined based on the probability and severity of each hazard. The combined HIRARC and Bowtie methods were effective in identifying complex risks, and selecting appropriate preventive and mitigation measures. Results showed that the main causes of occupational accidents were lack of supervision 33%, unsafe environmental conditions 26%, human error (22%), and incomplete use of personal protective equipment 19%. These results provide practical recommendations for improving construction safety management, through improved supervision, better compliance with PPE requirements, safer working conditions, worker awareness, regular risk assessments and controls.

Abstrak

Pekerjaan konstruksi memiliki risiko Keselamatan dan Kesehatan Kerja (K3) yang tinggi, terutama pada proyek pembangunan gedung. Penelitian ini bertujuan mengidentifikasi penyebab kecelakaan kerja pada Proyek Pembangunan Mall Bekasi menggunakan metode *Hazard Identification, Risk Assessment and Risk Control* (HIRARC) dan *Bowtie Analysis*. Pengumpulan data dilakukan melalui observasi lapangan, wawancara, dan kuesioner. Tingkat risiko ditentukan berdasarkan probabilitas terjadinya dan tingkat keparahan setiap bahaya. Kombinasi metode HIRARC dan *Bowtie* terbukti efektif dalam mengidentifikasi risiko yang kompleks serta memilih langkah-langkah pencegahan dan mitigasi yang tepat. Hasil penelitian menunjukkan bahwa penyebab utama kecelakaan kerja adalah kurangnya pengawasan 33%, kondisi lingkungan kerja yang tidak aman 26%, kesalahan manusia 22%, dan penggunaan alat pelindung diri (APD) yang tidak lengkap 19%. Temuan ini memberikan rekomendasi praktis untuk meningkatkan manajemen keselamatan konstruksi melalui penguatan pengawasan, peningkatan kepatuhan terhadap penggunaan APD, perbaikan kondisi kerja, peningkatan kesadaran pekerja, serta pelaksanaan penilaian risiko dan pengendalian secara berkala.

Kata kunci: analisis risiko, hirarc, bowtie, kecelakaan kerja, proyek bangunan

1. Introduction

The development of the construction industry is currently progressing at a rapid and unprecedented pace, driven by the fact that construction activities act as an essential and fundamental element in both national and global development. This sector not only provides the critical physical infrastructure and public facilities required to sustain modern society, but it also serves as a primary catalyst for economic growth, job creation, and urbanization. In its core definition, a construction project represents a complex, multidisciplinary series of highly coordinated activities related to the effort to design, build, or renovate a specific structure. These endeavors are inherently unique and bound by strict constraints; they must be successfully completed within a clearly defined and specific timeframe to achieve a predetermined goal [1]. *Consequently, the successful execution of such projects demands meticulous planning, rigorous resource management, and synergistic collaboration among various stakeholders to ensure that the ultimate objectives of time, cost, and quality are optimally fulfilled.*

In Indonesia, work accident cases from 2016-2024 *resulted in fatalities, total disabilities, partial disabilities, functional disabilities, and recovery after medical treatment. Throughout* 2019-2024, *the number of work accidents remained high as show in* ***Figure 1***. *To prevent and reduce workplace accidents, an OHS management system is required to be implemented in construction work activities to create a safe, efficient, and productive workplace* [2]. *The construction and manufacturing sectors contribute 32% of* *the total work accident cases in Indonesia each year* [8] [9] [10] [11]. *The number of work accidents in the construction sector is high and often considered unimportant, making construction projects have a greater risk of work accidents compared to other fields. Project management must analyze risk management, which is expected to reduce, protect against, and even eliminate the risk of workplace accidents (zero accidents) for workers* [12].

Risk is an integral part of life, especially in the business world where uncertainty and its associated risks are something that cannot be ignored, but must be carefully considered if success is desired [13]. Risk identification is carried out to gather potential risks that could occur during the execution of work. In risk management, it begins with risk identification to detail the types of risks that might arise from activities that will or are being carried out [14] [15].

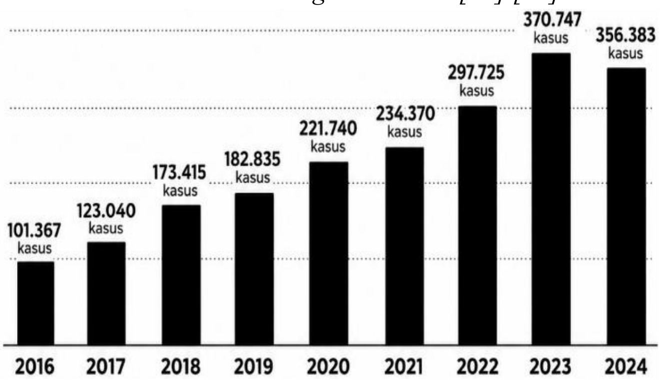

Figure 1. *Workplace Accident Trends in Indonesia* (2016–2024)
Source : BPJS Ketenagakerjaan

In this study, the methods used are the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) *method and Bow Tie Analysis* (BTA). *The* HIRARC *method is a process of identifying potential hazards that can occur in both routine and non-routine activities, followed by an assessment process based on the identified hazards or risks to determine the severity of a risk, thus assisting in the control process.* HIRARC *mitigates identified work risks* [3].

Meanwhile, the BTA *method is a technique that refers to a bow-tie-shaped diagram that simply illustrates or visualizes the risk events faced. The* BTA *method can be developed by combining two techniques: fault tree analysis* (FTA) *and event tree analysis* (ETA). *The combination of these two techniques provides an overview of the relationship between risk causes* (FTA) *and the relationship between risks and consequences* (ETA). *The use of the Bowtie Analysis method is very efficient because this method will identify the causes, effects, and controls (preventive and mitigating control measures) of potential workplace accidents, which can then be used to mitigate the risks of workplace accidents* [4].

In January 2025, *there were several minor workplace accidents at the Mall Building Construction Project in Bekasi, such as hands getting caught in steel during rebar work, scratched hands, eyes hit by wire fragments, and feet slipping, resulting in minor injuries. Work accidents occur due to ignorance and a lack of awareness of* OHS *in the workplace, causing workers to not use* PPE *correctly and engage in unsafe behavior. Additionally, management oversight of* OHS *implementation in the field is not strict enough, leading to numerous violations of safety procedures and weak sanctions for workers or contractors who do not comply with* OHS [5] [6].

This occurrence is a result of insufficient vigilance during work, the diminished mental or physical state of the workers, and the absence of tidiness and cleanliness at the building site [7]. *Therefore, this study aims to analyze* OHS *risks in the Mall Building Construction Project in Bekasi using the* HIRARC *method and Bow Tie Analysis* (BTA).

2. Method

The research was conducted in the Bekasi Mall Building Construction Project. The project is located in Bekasi City, West Java and will be implemented in 2024-2025. The project of the Bekasi Mall Building Construction is contracted by PT. XYZ. The mall is located in Bekasi and is easily accessible. The mall was developed on a 46,538 m² site with total building area of 87,458 m² and a net leasable area (NLA) of 42,744 m².

The data collection was done through a study of the work procedures of the project based on primary and secondary data obtained from field observations, interviews and questionnaires. Data were descriptively analysed and presented in tables and mathematical calculations with the Hazard Identification, Risk Assessment and Risk Control (HIRARC) and Bowtie Analysis (BTA) methods. The questionnaire data were processed using SPSS (Statistical Package for the Social Sciences) to produce descriptive statistics to facilitate risk analysis on the basis of the objectives and scope of the study.

Following the comprehensive identification of potential hazards across the operational lifecycle, the subsequent phase involved evaluating and quantifying the specific risk levels to establish a clear hierarchy of threat exposure. The entire risk assessment procedure was systematically conducted in strict alignment with the fundamental principles and risk management frameworks established in ISO 31000:2018. *Within this standardized approach, each* *identified hazard was rigorously evaluated and assigned a score based on two primary dimensions: likelihood (the probability or frequency of an adverse event occurring) and severity (the magnitude of consequence or potential damage resulting from the hazard). By integrating these two parameters, an overall risk rating and severity index were calculated to classify risks into manageable tiers (such as low, moderate, high, or critical), thereby enabling data-driven prioritization for subsequent risk mitigation and control strategies. To ensure objectivity, consistency, and repeatability in the scoring process, the standardized qualitative and quantitative criteria for the likelihood rating are comprehensively detailed in **Table 1**, whereas the corresponding thresholds for the severity rating are presented in **Table 2**.*

***Table 1.** Probability of Occurrence (likelihood)*

Level	Description	Definition Description
0	Rare	It might only happen under special conditions or once a year
1	Unlikely	It might happen under certain conditions, but it's unlikely
2	Possible	It might happen under certain conditions
3	Likely	It can happen in almost any condition
4	Almost Certainly	It can happen in all conditions

***Table 2**. Severity Level*

Level	Description	Definition Description
0	Insignificant	There's no loss, the material is very small
1	Minor	Minor injuries require first aid and can be handled directly at the scene, moderate material damage
2	Moderate	Lost workdays, required medical care, and material losses were quite significant
3	Major	The injury resulted in disability or total loss of bodily function, and the material losses were also significant
4	Extreme	Causing enormous material damage

From the questionnaire data collected were analyzed using the Importance Index, which consists of the Frequency Index (FI) and the Severity Index (SI) to determine the scales of likelihood and severity [16]. The Equation (1) is as follows:

$$Importance\ Index = F.I \times S.I \quad (1)$$

The Frequency Index (FI) represents the frequency level of risk factors affecting contractor performance. The Equation (2) for the Frequency Index (FI) is:

$$FI = \frac{\left(\sum_{(i=0)}^{4} a_i n_i\right)}{4N} \times 100 \quad (2)$$

The Severity Index (SI) represents the degree of impact or consequence of risk factors affecting contractor performance. The Equation (3) for the Severity Index (SI) is:

$$SI = \frac{\left(\sum_{(i=0)}^{4} a_i n_i\right)}{4N} \times 100 \quad (3)$$

Where:

a_i = *rating constant (0 to 4)*

n_i = *number of respondents selecting rating i*

i = 0, 1, 2, 3, 4, ..., n

N = total number of respondents

*The severity index classification used in this study is presented as follows in **Table 3**.*

***Table 3**. Severity index classification*

Scale	Classification	SI Range
0	Extremely Ineffective	$0\% < SI \leq 20\%$
1	Ineffective	$20\% < SI \leq 40\%$
2	Moderately Effective	$40\% < SI \leq 60\%$
3	Very Effective	$60\% < SI \leq 80\%$
4	Extremely Effective	$80\% < SI \leq 100\%$

Before conducting the HIRARC *analysis, the questionnaire responses were tested for validity using the Bivariate Pearson correlation method in* SPSS [17] [18]. *Validity testing is useful for determining the validity or suitability of the questionnaire used by the researcher to measure and obtain research data from respondents. Basis for Pearson validity test:*

Comparison of calculated r value with r table value

1. If calculated r value > r table = valid

2. If calculated r value < r table = tidak valid

HIRARC *is grouped into 3 stages: hazard identification, risk assessment, and risk control* [19]. *When implementing the* HIRARC *system, 4 simple steps are required:*

- *Classifying work activities*
- *Identifying work activities*
- *Assessing likelihood (analysing and predicting the possibility of hazards), estimating the probability of occurrence and severity of hazards*

- *Deciding whether the risk is tolerable* [20].

The steps that can be taken to create a bow tie diagram include:

- *Identify Bowtie Hazard*
  A hazard is something that is within or around that has the potential to cause harm. Hazards are located at the very top of the bowtie diagram.
- *Top Event*
  The top event emerges after the hazard is determined. Based on the bowtie analysis, the top event can also be called the risk event. The top event is selected before the actual damage-causing events.
- *Assess the Threats*
  Threats are something that will lead to a top event. Threats are located on the far left side of the diagram. Threats are something that has the potential to cause release from danger.
- *Asses the Consequences*
  Consequences are the impact of releasing a hazard; on a bowtie diagram, consequences are located on the far right side of the diagram.
- *Preventive and recovery Controls*
  A control is a protective measure to prevent a threat from releasing harm. In a bowtie diagram, the controls are located between the threats or consequences and the top event. Barriers are used to control unwanted scenarios that lead to damaging consequences.
- *Ecscalation Factor*
  The escalation factor is used to determine the facts about barriers that are not yet perfect and to re-evaluate them [21].

3. Result and Discussion

3.1 Characteristics by Ages

The distribution of respondent characteristics based on worker age can be seen in ***Figure 2*** *below. Based on the respondent identities of those who completed the questionnaire, the age distribution of the workers is as follows: 20% (4 people) are aged 21-25, 35% (7 people) are aged 26-30, 20% (4 people) are aged 31-35, 10% (2 people) are aged 36-40, 0% (0 people) are aged 41-45, 10% (2 people) are aged 46-50, and 5% (1 person) are aged 51-55.*

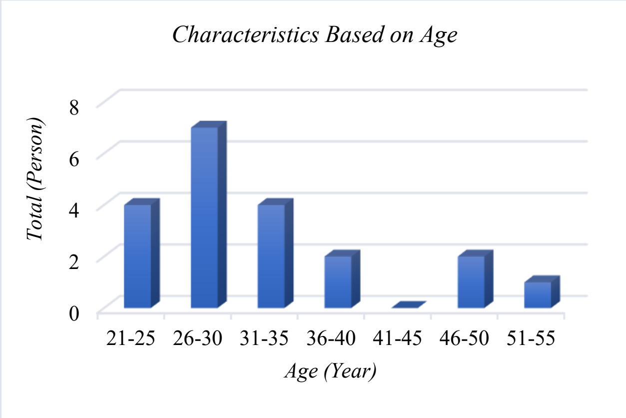

Figure 2*. Respondent Characteristics Diagram by Age*

3.2. Characteristics by Length of Service

The distribution of respondent characteristics based on work experience can be seen in ***Figure 3*** *below:*

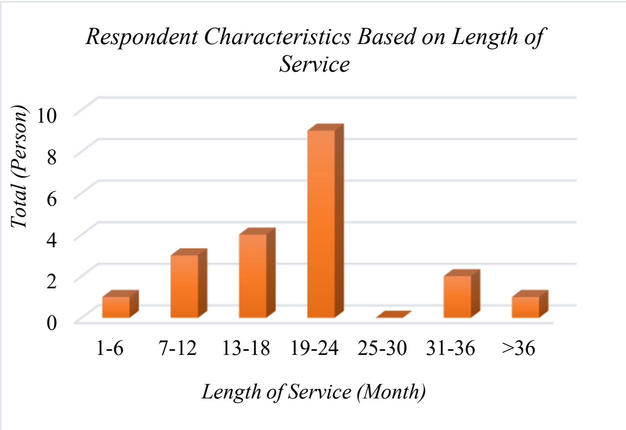

Figure 3*. Respondent Characteristics Diagram by Length of Service*

Based on the respondents' identities who completed the questionnaire, the respondents each had a tenure of 1-6 months (5% or 1 person), 7-12 months (15% or 3 people), 13-18 *months (20% or 4 people),* 19-24 *months (45% or 9 people), 25-30 months (0% or 0 people), 31-36 months (10% or 2 people), and > 36 months (5% or 1 person).*

3.3. Data Quality Using SPSS Software

3.3.1 Validity Test

The results of the variables confirmed by the respondents were analyzed using the Bivariate Person equation through the SPSS *program* [22].

This validity test is conducted to determine the relevance of the data or the validity of the respondents in assessing whether each statement is valid or not [23] [24], *which can be seen from the Pearson correlation of each job item with the following criteria:*

1. *This section contains answers to the question "what have you If the calculated r value is greater than the table r value, then the test item is declared valid."*
2. Testing *was conducted using a two-sided test with a significance level of 5% and a sample size of 20 respondents based on purposive sampling. The respondents consisted of Construction Managers, Site Engineers, Field Staff, and Occupational Safety and Health* (OSH) *Officers.*

The results of the data validity test can be seen in ***Table 4*** *below:*

Table 4*. Validity Test Results*

Element Statement	*r-value*	*r-table 5% (20)*	*Description*
P1	0.595	0.444	*valid*
P2	0.668	0.444	*valid*
P3	0.716	0.444	*valid*
P4	0.655	0.444	*valid*
P5	0.748	0.444	*valid*
P6	0.780	0.444	*valid*
P7	0.696	0.444	*valid*
P8	0.653	0.444	*valid*
P9	0.638	0.444	*valid*
P10	0.606	0.444	*valid*
P11	0.497	0.444	*valid*
P12	0.447	0.444	*valid*
P13	0.628	0.444	*valid*
P14	0.550	0.444	*valid*
P15	0.468	0.444	*valid*
P16	0.598	0.444	*valid*
P17	0.608	0.444	*valid*
P18	0.474	0.444	*valid*

Based on the validity test results above, the following values were obtained: if the calculated r-value for each question element is greater than the r-table value (0.444) *for the instrument items used, then it can be said to be valid* [25].

3.3.2 Reliability Test

The results of the reliability test can be seen in ***Table 5*** *below:*

Table 5*. Reliability Test Results*

Cronbach's Alpha	*N of Items*
0.897	18

A questionnaire is considered reliable when it produces a Cronbach's Alpha value > 0.6. Therefore, based on the reliability test results in Table 3.2, the Cronbach's Alpha value is 0.897 > 0.60, so the item is considered "Reliable".

3.4. Analysis of Factors Causing Occupational Accident Risk using the HIRARC *Method*

3.4.1 Hazard Identification

Identifying potential hazards that could occur during work activities is done methodically through a "hazard identification" process. Identifying potential risks is very helpful for being more careful when performing tasks. Identification is done using several techniques: passive techniques based on one's own experience, semiproactive techniques based on the experience of others, and proactive techniques by identifying hazards before they occur [14].

As for the work processes observed directly on the Bekasi Mall Building construction project, the following hazards can be identified:

a. *Foundation work involves several activities such as foundation excavation, which poses a risk of workers slipping.*
b. *Cutting piles using a grinder/cutting torch can cause wear and tear on the tool, leading to the risk of the grinder wheel breaking and exposure to dust and particles.*
c. *The excavation and backfilling process uses several heavy machines with various potential hazards. Stacking materials too close to the edge poses a risk of the pile walls collapsing.*
d. *Tower crane erection requires several pieces of equipment to be operated by competent operators. Failure to do so can lead to the risk of errors in component installation, causing structural failure.*
e. *Formwork installation using a saw for cutting the formwork poses a risk of punctures and cuts.*
f. *Rebar work can pose a risk of being punctured by sharp rebar ends.*
g. *Installing the roof structure on a sloping and slippery surface increases the risk of workers falling from a height.*
h. *Installing the ceiling with a gypsum drilling tool poses a risk of workers experiencing respiratory problems, even asphyxiation.*
i. *Installing precast panels with improper lifting techniques can lead to muscle or bone injuries.*

3.4.2 Risk Assessment

The purpose of risk assessment is to measure the likelihood of danger (the magnitude of the risk) from workplace accidents.

In the construction process of the Bekasi Mall Building Project by PT. XYZ, there are 27 safety risks identified from the analysis. Where at the low level, which is in the green column, 7 types of hazard risks are found, namely in jobs 1a, 1d, 1f, 2b, 4b, 6b, and 6c.

At the medium level, which is in the yellow column, 10 types of hazard risks are found, namely 1b, 1c, 1e, 2c, 4a, 4c, *5b, 5c, 6a, and 7b. At this level, it is still tolerable, but it also requires awareness of occupational safety and health itself.*

At the high level, which is in the orange-colored column, 9 types of hazard risks were found: 2a, 2d, 2e, 3a, 3b, 3c, 5a, 7a, and 7c. This risk level requires more control by increasing vigilance and using project tools according to the specified SOP. At the extreme level, which is in the red column, there is one type of hazard risk: 2f. If this hazard risk category occurs, it must be stopped immediately and follow-up action must be taken at that time.

3.4.3 Risk Control

All hazards identified during the hazard identification process are subject to risk control, which considers risk ratings to establish priorities and control methods. Here are the results of risk control:

- *a. Provide safety fences and safety nets for work at height.*
- *b. Conduct routine inspections of the structure to identify signs of instability and install warning signs.*
- *c. Operators must be certified as competent and have received training on working techniques.*
- *d. Ensure the equipment is in good condition through daily inspections.*
- *e. Use complete PPE according to the type of work.*
- *f. Provide barriers and exclusion zones around the installation area.*
- *g. Use lifting aids to reduce injuries during lifting.*
- *h. Ensure the work area is safe, clean, and tidy.*

3.5. Analysis of the Causes of Occupational Accident Risk Using the Bowtie Method

*The results of the questionnaire assessing the likelihood and severity of perception and the residual risk after the proposed control measures are presented in **Table 6**.*

*Based on the comprehensive risk assessment results presented in **Table 6**, one specific hazard was identified and classified at an "extreme" risk level, namely variable 2f, which pertains to the critical danger of workers falling from a height during the complex process of crane installation. In the context of construction management and occupational safety, risks categorized as "extreme" possess a highly disruptive and dominant potential. They can lead to catastrophic consequences, including fatal workplace accidents, severe legal liabilities, and significant disruptions to the project schedule. Given its dominant nature and the severe threat it poses to the overall project implementation, this specific variable mandates immediate and prioritized intervention. Therefore, it is highly scientifically and practically necessary to conduct a more in-depth reanalysis of its underlying root causes, potential cascading impacts, and the effectiveness of existing risk control measures. To achieve this, the Bow Tie Analysis method will be systematically employed.*

This method is specifically selected because it provides a highly visual, structured framework that effectively maps the causal pathways between the specific threats, the top event, and the resulting consequences, while simultaneously evaluating the robust preventive and mitigative barriers required to ensure operational safety.

***Table 6**. Recapitulation of Likelihood and Severity Index*

No	*Likeli-hood Index (LI)*	*Rank*	*Seve-rity Index (SI)*	*Rank*	*Category Matriks*	*Residual Risk*
1a	20%	0	40%	1	R	-
1b	25%	1	43%	2	S	-
1c	40%	1	43%	2	S	-
1d	35%	1	40%	1	R	-
1e	70%	3	18%	0	S	-
1f	30%	1	28%	1	R	-
2a	42%	2	48%	2	T	*Low*
2b	40%	1	37%	1	R	-
2c	40%	1	45%	2	S	-
2d	32%	1	68%	3	T	*Medium*
2e	38%	1	68%	3	T	*Medium*
2f	33%	1	85%	4	E	*Medium*
3a	45%	2	43%	2	T	*Low*
3b	42%	2	55%	2	T	*Low*
3c	33%	1	70%	3	T	*Medium*
4a	38%	1	52%	2	S	-
4b	35%	1	35%	1	R	-
4c	25%	1	48%	2	S	-
5a	38%	1	73%	3	T	*Medium*
5b	23%	1	58%	2	S	-
5c	45%	2	25%	1	S	-
6a	32%	1	53%	2	S	-
6b	38%	1	33%	1	R	-
6c	35%	1	35%	1	R	-
7a	37%	1	65%	3	T	*Medium*
7b	32%	1	43%	2	S	-
7c	37%	1	75%	3	T	*Medium*

After obtaining the extreme (dominant) risk variables from the risk level assessment, the next step is to conduct an analysis using the bowtie method to analyze the causes, impacts, and controls of these risks. One variable with an "extreme" risk level was identified, which is variable 2f. The following is a bowtie diagram of the selected extreme risk:

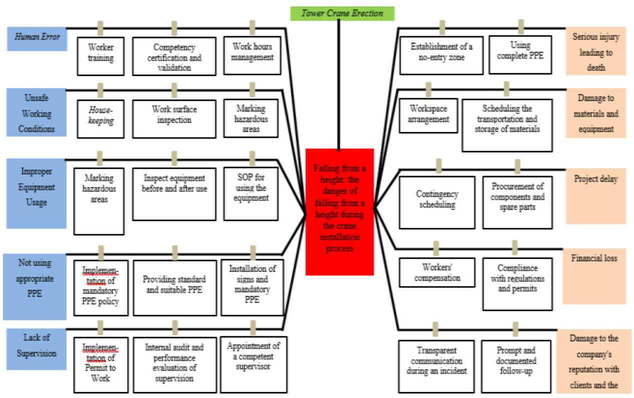

***Figure 4**. Results of the Bow Tie Analysis Method*

*Based on **Figure 4**, the results of the risk analysis using the bowtie method are as follows:*

Hazard : Tower Crane Erection

Risk : Falling from a height: the danger of falling from a height during the crane installation process.

The cause is:

1. Human Error

Control:

- *Worker Training*
- *Competency Certification and Validation*
- *Worling Hours Management*

2. Unsafe Working Conditions

Control:

- *Housekeeping*
- *Inspection of the Work Surface*
- *Marking of Hazardous Areas*

3. Inappropriate Equipment Usage

Control:

- *Calibration and Load Test Document*
- *Equipment Inspection Before and After Use*
- *SOP for Equipment Usage*

4. Not Using Appropriate Personal Protective Equipment (PPE)

Control:

- *Implementation of Mandatory PPE Policy*
- *Provision of Standard and Suitable PPE*
- *Installation of Mandatory PPE Signs and Markings*

5. Lack of Supervision

Control:

- *Implementation of a Work Permit System*
- *Internal Audits and Performance Evaluation of Supervision*
- *Appointment of Competent Supervisors*

Consequence

1. Serious Injury or Death

Mitigation:

- *Establishing an Exclusion Zone*
- *Using Complete Personal Protective Equipment (PPE)*

2. Material and Equipment Damage

Mitigation:

- *Establishing a Work Area*
- *Scheduling Material Transportation and Storage*

3. Project Delay

Mitigation:

- *Contingency Schedule Development*
- *Procurement of Backup Components and Tools*

4. Financial Losses

Mitigation:

- *Worker's Compensation Insurance*
- *Compliance with Regulation and Permits*

5. Damage to the Company's Reputation with Clients and the Public

Mitigation:

- *Transparent Communication During Incidents*
- *Rapid and Documented Follow-Up*

3.6. Expert Validation

*The results of expert validation of the occupational accident risk assessment instrument can be seen in **Table 7** below:*

***Table 7**. Expert Validation Results*

No	Factor	Variable	Response
1.	Worker	Lack of job training	Agree
		Lack of worker experience	Agree
		Fatigue while working	Agree
2.	Environment	Unsafe working conditions	Agree
3.	Equipment	Improper use of equipment	Agree
		Lack of maintenance	Agree
4.	Management	Lack of supervision over workers	Agree
		Lack of communication	Agree

4. Conclusion

Based on the presentation and discussion of the research on the Analysis of Factors Causing Occupational Accidents in the Mall Building Construction Project in Bekasi, it can be concluded that:

1. *The factors causing the risk of occupational accidents in this study using the HIRARC and Bowtie methods are:*
   a. *Under-trained, less competent workers who are fatigued during work, thus increasing the likelihood of operational errors*
   b. *Unsafe working conditions and failure to meet safety standards also increase the risk of accidents*
   c. *Using the wrong tools in the work process causes potential hazards*
   d. *Not using PPE completely and correctly*
   e. *Lack of supervision from management or supervisors, leading to a lack of discipline and effectiveness.*
2. *The following are actions to control occupational accident risks:*
   a. *Provide safety fences and safety nets when working at heights*
   b. *Use complete and appropriate personal protective*
   c. *Conduct regular inspections of tools to ensure everything is in good condition, safe, and fit for use*
   d. *Provide barriers and establish exclusion zones around the work area*
   e. *Keep the work area clean and tidy to avoid accidents due to tripping or slipping*
   f. *Provide regular safety training to workers.*

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