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Occupational Health and Safety Risk Management in Toll Road Construction

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ABSTRACT

Construction projects carry substantial risk of work accidents. This study aims to (1) identify hazards in project activities, (2) assess and rank the associated risks, and (3) determine appropriate risk controls, using Hazard Identification, Risk Assessment, and Determining Control (HIRADC) combined with Job Safety Analysis (JSA), with Toll Road X as the case study. Of the hazards identified, none were classified as large risk; 10 were classified as medium risk and 12 as small risk. The six highest-risk findings, all medium risk, were: tripping, slipping, and falling during measurement/survey; dust exposure causing eye irritation during soil filling; slipping/falling from height during excavation; being struck by iron/steel bars; cuts from using a Bar Bender; and stepping on debris or metal during spreading. These risks may result in lost working days, permanent or partial disability, moderate environmental damage, material losses, and medical costs. Recommended risk controls include occupational health and safety (OHS) training, safety audits, use of personal protective equipment (PPE), implementation of JSA, and adoption of appropriate construction methods to reduce work accident risk.

Keywords: Risk management; work accident; SMKK; toll road

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1. INTRODUCTION

Along with the rapid growth of construction development, the role of work accident risk control has become increasingly important. Every construction project, regardless of its type, carries inherent risk. Risk is a contributing factor to unexpected conditions that may result in loss, damage, or harm [1], [2]. The larger the scale of a project, the greater the potential risk, which, if not properly managed, may hinder project implementation [3]. Early identification and mitigation of hazards at the design stage, rather than relying solely on measures applied during execution, have likewise been shown to reduce construction safety risks [20]. To ensure and protect the safety and health of workers, preventive efforts against occupational accidents and work-related diseases in construction projects are required, as stipulated in the Regulation of the Minister of Public Works and Housing (PUPR) No. 10 of 2021. The Construction Safety Management System (SMKK) is an integral part of the labor protection system for construction services, aimed at minimizing and avoiding the risk of moral and material losses, loss of working hours, as well as safeguarding human safety and the surrounding environment, ultimately supporting effective and efficient performance improvement in the construction process [4]. Effective SMKK implementation has similarly been found to positively influence workers' safety behavior on construction projects [26].

Several methods can be employed for risk analysis, such as HAZOP (Hazard and Operability Study) [5], HIRARC (Hazard Identification, Risk Assessment, and Risk Control) [6]-[8], and HIRADC (Hazard Identification, Risk Assessment, Determine Control) [9]-[13]. Multicriteria decision-making approaches, such as the Analytic Network Process (ANP), have also been used to prioritize interconnected construction safety risks based on their frequency and severity [25]. According to the OHSAS 18001 2007 [14] guidelines and PUPR Ministerial Regulation No. 10 of 2021, an organization must establish procedures and undertake Hazard Identification, Risk Assessment, and Determining Control, which constitute essential sub-elements of a construction safety management system, as they relate directly to hazard prevention and control efforts used to define construction safety objectives and plans. Work accidents may arise from various potential hazards present in the work environment. These potential hazards can be identified to determine control priorities based on the level of occupational accident risk, thereby enabling the classification of hazard categories to facilitate the evaluation process as part of occupational health and safety risk management [4].

The construction of toll roads presents several potential risks, arising for instance from the use of heavy equipment, work at height, hand entrapment, and electric shock, among others, which have been identified as leading causes of fatal construction accidents in Indonesia [19]. Such risks may adversely affect the achievement of project objectives, including budget and schedule performance, thus necessitating occupational health and safety risk management in construction projects. Based on the aforementioned considerations, this study aims to review labor safety risk management in toll road projects by: 1) identifying activities that may pose potential risks; 2) determining risk rankings; 3) assessing the highest possible risk levels; and 4) identifying possible risk control measures. The case study in this research is Toll Road Project X.

2. METHOD

The research process was conducted using a structured and systematic approach to ensure data accuracy and validity. The overall workflow of this study is depicted in Figure .1.

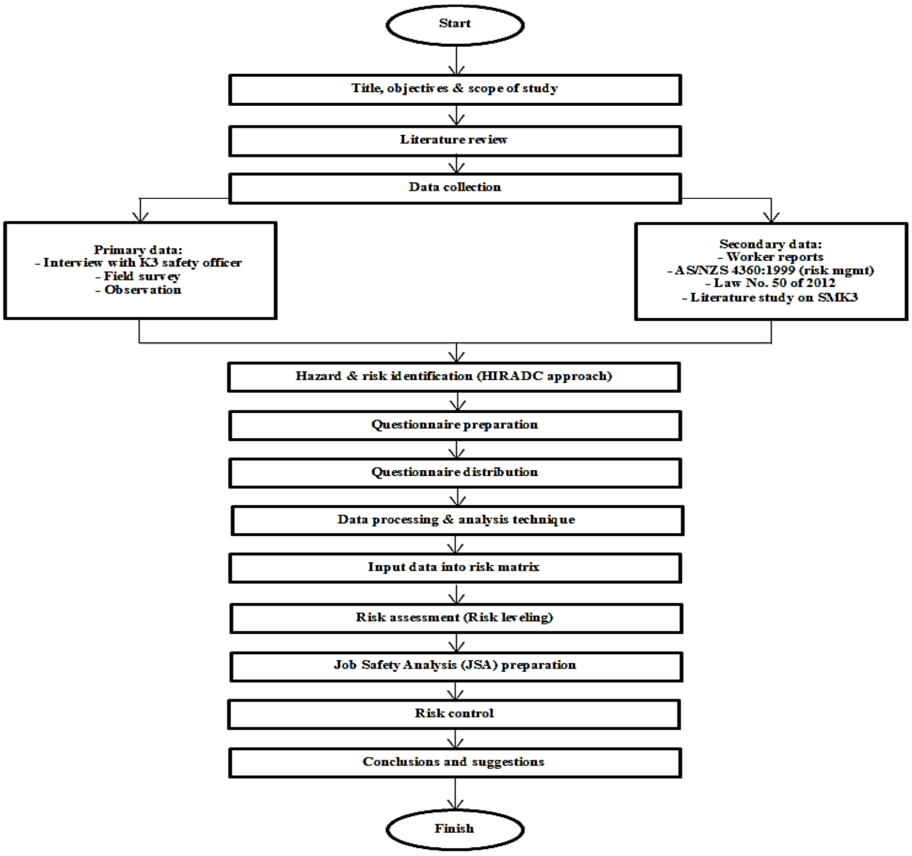

Figure 1. Research Flowchart

The method used in this study is Hazard Identification, Risk Assessment, and Determining Control (HIRADC), a method employed to prevent or minimize work accidents. The HIRADC process is divided into three stages: 1) hazard identification; 2) risk assessment; and 3) determining control (hazard control). From the results of risk identification and HIRADC calculations, the risk levels associated with each work activity in the project under study, as well as the highest risk level, were obtained. Hazard identification is the process of detecting potential hazards that may lead to work accidents and occupational diseases. Subsequently, using the Job Safety Analysis (JSA) method, work steps are broken down to identify potential hazards so that solutions can be developed to minimize possible risks [15]. Beyond its use as a stand-alone hazard-identification tool, JSA has also been shown to support decentralised, contextual risk handling within multi-organisational construction projects [24].

The primary data used in this study consisted of: 1) observation, 2) documentation, 3) questionnaires, and 4) interviews. Meanwhile, the secondary data used included: 1) AS/NZS 4360:1999 on Risk Management [16]; 2) OHSAS 18001:2007 on Occupational Health and Safety Management Systems [14]; 3) OHSAS 18002:2008 on OHS Management System Guidelines [17]; 4) Indonesian Law No. 1 of 1970 on Work Safety [18]; 5) Regulation of the Minister of PUPR No. 10 of 2021 on Construction Safety Management System Guidelines [4]; and 6) relevant literature on the Construction Safety Management System (SMKK). AS/NZS 4360:1999 and OHSAS 18001:2007 were retained as baseline standards because the safety policies, operational procedures, and risk assessment matrices currently applied at the project site are directly structured around them. The validity test on the probability factor is a testing procedure conducted on the content of an instrument, aimed at measuring the accuracy of the instrument used, as well as determining the extent to which the measurement instrument performs its measuring function precisely and accurately. In this study, instrument validity was tested using the Pearson Product Moment correlation test with the SPSS application program. A reliability test was subsequently conducted to measure the consistency of respondents' answers by correlating their responses.

3. RESULTS AND DISCUSSION

The respondents totalled 67 people, with the following educational backgrounds: 31% held a Bachelor's degree (S1), 8% held a Diploma (D3), 31% had completed senior high school (SMA), 18% had completed junior high school (SMP), and 12% had completed elementary school (SD). In terms of position, 3% were Site Operational Managers, 3% were Project Managers, 10% were OHS Officers, 70% were heavy equipment operators, and 13% were Supervisors. Risk identification was carried out using various sources, including interviews with project stakeholders, documents, and field observations. The risk identification results yielded the risk variables that may occur during project implementation, as presented in Table 1.

Table 1. Risk Identification Variables

No	Risk Variable
	Measurement Work
1	Stepping on a nail during measurement/survey
2	Animal bites during measurement/survey; venom that may cause paralysis
3	Tripping, slipping, and falling hazards during measurement/survey
4	Workers slipping/falling from height during measurement/survey
	Excavation Work
5	Excavator overturning from height during excavation
6	Workers exposed to dust during the soil-filling process, causing eye irritation
7	Workers slipping/falling from height during excavation
8	Accidents caused by equipment mobilization
	Soil Filling Work
9	Incidents involving heavy equipment during the soil-filling process
10	Vehicles colliding with or being struck by vehicles entering/exiting the site
11	Collisions between project vehicles during the soil-filling process
12	Vehicles/heavy equipment overturning during the soil-filling process
	Spreading Work
13	Dozer skidding during soil-spreading operations
14	Workers stepping on debris/metal during the spreading process
15	Dust during spreading causing eye irritation and respiratory problems for workers
16	Noise from compactors/heavy equipment affecting workers' hearing
	Compaction Work
17	Damage to machinery/equipment used in the compaction process
18	Workers/machinery skidding during the compaction process
19	Speedy/carbide sand-cone test equipment causing respiratory problems
20	Continuous vibration from compactors/smooth rollers causing worker fatigue and cramps
	Reinforcement (Rebar) Work
21	Workers being punctured/struck by iron/steel bars
22	Workers sustaining minor burns from hot iron/steel bars
23	Workers sustaining cuts while using a Bar Bender

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No	Risk Variable
24	Steel offcuts from the bar cutter striking workers during cutting
25	Workers receiving electric shocks while cutting steel with a bar cutter
	Formwork Work
26	Workers' hands being struck or pinched by formwork
27	Formwork design errors or formwork installation not matching the working drawings
28	Workers not wearing gloves during formwork work
29	Falls from height during formwork dismantling
	Concreting (Pouring) Work
30	Formwork breaking
31	Workers being struck by mixer vehicles during maneuvering
32	Workers being struck by the excavator's swing arm
33	Concrete quality not meeting specifications

3.1. Validity Test for Probability

The instrument validity test was conducted using the Pearson Product Moment correlation, the results of which are presented in Table 2.

Table 2. Validity Test for Probability

ΣX	ΣY	ΣX²	ΣY²	ΣXY
213	1981	709	60787	632

The resulting correlation coefficient was rxy = 0.110. From Table 2, for variable X1, the calculated r-value for the item regarding stepping on a nail during measurement/survey was (0.11), which was lower than the r-table value (0.24). This result indicates that the questionnaire item for this specific hazard was invalid as a measurement instrument and was subsequently excluded from further statistical analysis. The same formula was applied to variable X2 and subsequent variables to determine which were valid and which were not. After completing the validity analysis for the probability factor, an overall r-table value of 0.24 was obtained, with the following decision criteria used for the validity test:

r-calculated > r-table → valid

r-calculated < r-table → invalid

Meaning the calculated r-value must exceed the r-table value. Based on the results of the instrument trial, it was concluded that of the 33 hazard items related to work accidents, 27 items were valid, while 6 items were invalid, namely: 1) stepping on nails during survey and measurement work; 2) collisions involving project vehicles during backfilling operations; 3) foot injuries from stepping on debris or scrap metal during land leveling; 4) minor thermal burns from handling hot steel elements; 5) inadequate supervision ensuring formwork design and installation match working drawings; and 6) non-conforming concrete quality.

3.2. Validity Test for Severity

The validity testing procedure for the severity factor followed the same steps as for the probability factor, conducted in several stages until all hazard types were determined to be valid or invalid. Any invalid hazard type was subsequently removed. A summary of the severity validity test results is presented in Table 3, yielding rxy = 0.463. The severity validity test identified 9 invalid items, namely: 1) stepping on nails during survey/measurement work; 2) workers slipping or falling from height during soil excavation; 3) brake failure on heavy project vehicles during backfilling; 4) collisions involving project vehicles during backfilling; 5) machinery/equipment failure during soil compaction; 6) falling from height during formwork dismantling; 7) workers being struck by mixer trucks during maneuvering; 8) workers being hit by the excavator's swing arm; and 9) non-conforming concrete quality.

Table 3. Validity Test for Severity

ΣX	ΣY	ΣX²	ΣY²	ΣXY
171	1822	479	52044	4801

3.3. Reliability Test for Probability

Once the valid variables had been identified, a reliability test was conducted to determine the consistency of the questionnaire used, based on the following decision criteria. A variable is considered reliable if its Cronbach's Alpha value exceeds 0.6, as follows:

Cronbach's Alpha > 0.6 → consistent

Cronbach's Alpha < 0.6 → inconsistent

The reliability test was conducted on the entire set of 33 items comprising the probability factor instrument, as Cronbach's Alpha is computed at the scale level to assess the internal consistency of the questionnaire as a whole, rather than being recalculated separately for each item found valid. The reliability test results for the probability factor, as shown in Table 4, indicate a Cronbach's Alpha value of 0.896, which exceeds the 0.6 threshold. This confirms that the questionnaire instrument for the probability factor is consistent and reliable. It is important to note that the N of Items value of 33 in Table 4 refers to the total number of items entered into the reliability procedure, and is separate from the number of variables (27) that were subsequently determined to be valid based on the item-total correlation criterion in the validity test. Accordingly, of the 33 items assessed, 27 valid variables were retained for further analysis.

Table 4. Reliability Test for Probability

Cronbach's Alpha	N of Items
0.896	33

3.4. Reliability Test for Severity

The reliability testing procedure for the severity factor followed the same procedure as for the probability factor. The severity validity test results are presented in Table 5, and the reliability test was likewise conducted on the entire set of 33 items comprising the severity factor instrument. The reliability test results, as shown in Table 5, indicate a Cronbach's Alpha value of 0.812, which exceeds the 0.6 threshold, confirming that the questionnaire instrument for the severity factor is consistent and reliable. As with the probability factor, the N of Items value of 33 in Table 5 refers to the total number of items entered into the reliability procedure, and is separate from the number of variables (25) that were subsequently determined to be valid based on the item-total correlation criterion in the validity test. Accordingly, of the 33 items assessed, 25 valid variables were identified for further analysis.

Table 5. Reliability Test Results for Severity

Cronbach's Alpha	N of Items
0.812	33

3.5. Selection of Hazard Types Passing Both Tests

After conducting the validity and reliability tests for the probability and severity of each hazard type in every work division, the hazard types that passed both tests were compiled to obtain accurate and reliable data. Table 6 presents a summary of the hazard types that passed both tests, showing that 69%, or 22 out of the total 33 hazard types, passed both the validity and reliability tests.

Table 6. Summary of Hazard Types That Passed Both Tests

No	Division	Probability Validity Test	Severity	Passed Both
1	Measurement Work	3	4	3
2	Excavation Work	4	4	4
3	Soil Filling Work	3	2	2
4	Spreading Work	3	3	3
5	Compaction Work	4	3	3
6	Reinforcement Work	3	5	3
7	Formwork Work	4	3	3
8	Concreting Work	3	1	1

3.6. Risk Matrix

Once the average probability and severity values were obtained, the next step was matrix processing. The risk score was calculated by multiplying the average probability value by the average severity value. Based on the probability and severity data, risk mapping could be conducted to classify each risk into one of three categories: High (H), with a score of 15–25; Medium (M), with a score of 5–12; and Low (L), with a score of 1–4, in accordance with the risk matrix set out in PUPR Ministerial Regulation No. 10 of 2021 [4]. OHSAS 18002 [17], meanwhile, classifies risk into four levels: Extreme, High, Medium, and Low.

3.7. Risk Assessment

After selecting the hazard types that passed both tests, the next step was to conduct a risk assessment by averaging the responses of all respondents from each division based on the probability and severity factors. The average probability value was multiplied by the average severity value to obtain the risk score. Table 7 presents the highest-ranked risks. Following hazard identification, a risk assessment was carried out, identifying six hazards in the highest risk category that directly cause work disruptions. These risks carry severe consequences, including lost workdays, permanent or partial disability, moderate environmental damage, major financial losses, medical expenses, and the need for professional medical care.

It is important to note that the risk score calculation in Table 7 is based solely on the 27 probability variables and 25 severity variables that were confirmed valid and reliable through the preceding validity and

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reliability tests. Hazard variables that did not meet the validity criterion were excluded from this quantitative scoring process and are not reflected in Table 7.

Risk control was subsequently carried out using Job Safety Analysis (JSA), a method used to analyze the tasks and procedures within a project through detailed step-by-step breakdowns of each work stage. This method is now widely used in projects, particularly those funded or managed by the government, in accordance with the guidelines set out in PUPR Ministerial Regulation No. 10 of 2021 [4].

Unlike the quantitative risk scoring in Table 7, the Job Safety Analysis presented in Table 8 is a qualitative hazard identification and control tool. Its purpose is to comprehensively map the potential hazards, risks, and corresponding control measures for every task within each work stage, regardless of whether a given hazard variable met the statistical validity and reliability criteria applied to the questionnaire instrument. Consequently, Table 8 intentionally includes hazard variables that were excluded from the quantitative analysis in Table 7, as JSA is intended to support comprehensive occupational safety planning rather than to replicate the filtered results of the questionnaire-based risk scoring. This distinction ensures that no potential hazard identified in the field is overlooked during the development of safety control measures, even if it did not meet the statistical threshold used to prioritize risks numerically.

Table 7. Highest Risk Assessment Results

No	Risk Variable	Probability	Severity	Score	Matrix
1	Tripping, slipping, and falling hazards during measurement/survey	3	3	9	M
2	Workers exposed to dust during the soil-filling process, causing eye irritation	3	3	9	M
3	Workers slipping/falling from height during excavation	3	3	9	M
4	Workers being punctured/struck by iron/steel bars	3	3	9	M
5	Workers sustaining cuts while using a Bar Bender	3	3	9	M
6	Workers stepping on debris/metal during the spreading process	3	3	9	M

3.8. Job Safety Analysis (JSA)

Hazards and risks were identified using the JSA method. Its objective is to undertake specific measures to prevent incidents, through effective identification (close observation, understanding of the work being observed, and repeated monitoring). Discussions with personnel experienced in the observed work were also conducted. Hazard identification was carried out on elements of the work environment, such as tools/machinery, materials, and processes, to detect potential hazards within the project. Risk assessment and control recommendations were then formulated for each hazard type to reduce the potential for work accidents and their resulting losses to the company and its workforce. This JSA was conducted in accordance with PUPR Ministerial Regulation No. 10 of 2021 [4], under which risk levels are classified into three categories: High (H), Medium (M), and Small (S). Table 8 presents the risk management results using the JSA method as applied during project implementation.

Table 8. Job Safety Analysis (JSA)

No	Work Stage	Potential Hazard	Risk	Control	Level HoC
1	Measurement	Stepping on a nail during measurement/survey	Bleeding of the foot and possible amputation if not treated immediately	Use PPE (safety shoes) provided during measurement work	PPE
		Animal bites during measurement/survey; venom that may cause paralysis	Poisoning if the animal's venom is paralytic	Use PPE such as thick clothing, gloves, thick trousers, and safety shoes to minimize the risk of bites	PPE
		Tripping, slipping, and falling hazards during measurement/survey	Injury or fracture to body parts	All workers must pay attention to the work area and stay alert to tripping, slipping, and falling hazards	Administrative
		Workers slipping/falling from height during measurement/survey	Injury or fracture to body parts	Use PPE such as a properly secured safety harness	PPE
2	Excavation	Excavator overturning from height during excavation	Excavator falling onto workers	Provide OHS signage on-site. Workers must keep a safe distance from the excavator during excavation. Ensure the excavator operator is experienced	Administrative
		Workers exposed to dust during the soil-filling process, causing eye irritation	Eye irritation causing impaired vision	Use PPE such as provided safety glasses	PPE

No	Work Stage	Potential Hazard	Risk	Control	Level HoC
		Workers slipping/falling from height during excavation	Injury to body parts; sudden death	Use provided safety harnesses	PPE
		Accidents caused by equipment mobilization	Collisions between heavy equipment during mobilization	Assign personnel to direct heavy-vehicle entry and exit during mobilization; install warning signage	Administrative
3	Soil Filling	Incidents involving heavy equipment during the soil-filling process	Vehicle striking a worker	Check the condition of heavy equipment before and after use	Engineering
		Vehicles colliding with or being struck by vehicles entering/exiting the site	Workers sustaining serious injury; workers trapped by damaged vehicles	Provide personnel at vehicle entry/exit intersections to prevent accidents	Administrative
		Collisions between project vehicles during the soil-filling process	Sudden death; truck damage	Provide an operator to guide incoming equipment	Administrative
		Vehicles/heavy equipment overturning during the soil-filling process	Workers sustaining serious injury; sudden death on-site	Supervision must be provided	Administrative
4	Spreading	Dozer skidding during soil-spreading operations	Workers sustaining serious injury; sudden death on-site	Analyze the soil structure the dozer will traverse; select an experienced dozer operator	Administrative
		Workers stepping on debris/metal during the spreading process	Bleeding of the sole of the foot; lacerations to the foot	Use PPE such as safety shoes provided by the company	PPE
		Dust during spreading causing eye irritation and respiratory problems for workers	Eye irritation causing impaired vision; shortness of breath	Use PPE such as masks and safety glasses specified by the K3 team	PPE
		Noise from compactors/heavy equipment affecting workers' hearing	Hearing exposed to noise; ruptured eardrum	Use PPE such as soundproof ear protection	PPE
5	Compaction	Damage to machinery/equipment used in the compaction process	Injury to body parts	Regularly check and calibrate equipment, including equipment past its calibration period	Engineering
		Workers/machinery skidding during the compaction process	Workers sustaining injury to body parts	Use appropriate PPE; check equipment condition before use	PPE
		Speedy/carbide sand-cone test equipment causing respiratory problems	Problems with the sense of smell; dizziness; fainting	Use PPE such as a thick mask	PPE
		Continuous vibration from compactors/smooth rollers causing worker fatigue and cramps	Worker fatigue; hand cramps	Workers should warm up before starting activities to avoid these effects	Administrative
6	Reinforcement (Rebar) Work	Workers being punctured/struck by iron/steel bars	Head injury; bruising to body parts; wounds to body parts	Use complete PPE from head to foot	PPE
		Workers sustaining minor burns from hot iron/steel bars	Skin bruising; skin burns	Use protective PPE such as thick clothing and gloves	PPE
		Workers sustaining cuts while using a Bar Bender	Cuts to the hands	Use PPE such as gloves	PPE
		Steel offcuts from the bar cutter striking workers during cutting	Head injury if steel fragments strike the head; puncture wounds to body parts	Inspect the bar cutter for suitability before use; wear complete PPE	Engineering & PPE
		Workers receiving electric shocks while cutting steel with a bar cutter	Electric shock; sudden death	Ensure the body is not wet	Administrative
7	Formwork	Workers' hands being struck or pinched by formwork	Cuts to the hands	Wear PPE such as gloves	Administrative
		Formwork design errors or formwork installation not matching the working drawings	Design shape not conforming to specifications	Supervision must ensure formwork design and installation conform to the working drawings	PPE

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No	Work Stage	Potential Hazard	Risk	Control	Level HoC
		Workers not wearing gloves during formwork work	Cuts/lacerations/tears to the hands	All workers must wear gloves	Administrative
		Falls from height during formwork dismantling	Injury to workers below	Ensure the area around the formwork to be dismantled is safe	PPE (harness)
8	Concreting (Pouring)	Formwork breaking	Formwork rendered unusable; unable to withstand prolonged use in the channel	Ensure formwork is installed securely, under pouring supervision	Administrative
		Workers being struck by mixer vehicles during maneuvering	—	Ready-mix truck maneuvers are guided to the correct pouring position	Administrative
		Workers being struck by the excavator's swing arm	Injury	No one is permitted to pass beneath the excavator bucket while spreading concrete	Administrative
		Concrete quality not meeting specifications	—	A signalman guides the crane operator during lifting operations. Concrete samples are taken and laboratory analysis performed to ensure concrete quality meets the standard	Engineering & Administrative

The JSA method can be used to identify hazards, determine risk levels, and establish steps and control measures for risk mitigation. Consequently, applying the JSA method for project control will reduce the level of work accident risk on the project. The implementation of occupational health and safety management is one of the key efforts in ensuring the successful execution of the SMKK program on toll road construction projects.

4. CONCLUSION

Occupational health and safety management is a critically important aspect of construction work implementation, encompassing the identification, ranking, assessment, and control of risk, and constitutes a core part of the Construction Safety Management System (SMKK). In this study, risk was classified into three categories: large, medium, and small. The risk assessment results for the Toll Road X project indicated no large risks. Medium risk represented the highest risk level found on this project, comprising six findings: (1) tripping, slipping, and falling hazards during measurement/survey; (2) workers exposed to dust during the soil-filling process, causing eye irritation; (3) workers slipping/falling from height during excavation; (4) workers being punctured/struck by iron/steel bars; (5) workers sustaining cuts while using a Bar Bender; and (6) workers stepping on debris/metal during the spreading process. The resulting impacts include loss of working days, permanent/partial disability, moderate environmental damage, substantial material losses, and significant medical costs due to the need for medical treatment. Risk control efforts undertaken include OHS training and counseling [23], audits to reduce risk levels, the use of Personal Protective Equipment (PPE) [21], [22], the implementation of Job Safety Analysis (JSA) [24], and the application of appropriate implementation methods to reduce the level of work accident risk [20], [25].

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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