
EFFORTS TO PREVENT WORK ACCIDENTS WITH THE FAILURE MODE AND EFFECT ANALYSIS (FMEA) METHOD

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ABSTRACT

Introduction: The Solo Balapan-Kadipiro elevated line project is considered to have a high risk of danger because the project is in direct contact with the highway and is located between residential areas. Hence, it can cause work accidents for employees or workers at the project site. This study aims to identify the risks of precast channel installation work, Geotextile installation. **Method:** Roadwork uses the Failure Mode and Effect Analysis (FMEA) method and carries out a risk control strategy to prevent work accidents in the work area. Risk identification in construction projects is carried out based on field observations and risk observations in the hazard identification risk assessment and risk control (HIRARC) documents and job safety analysis (JSA) documents prepared by HSE, to be further validated through a preliminary questionnaire to respondents. Furthermore, the respondents assessed the Severity, Occurrence, and detection levels by filling out the main questionnaire using a predetermined rating scale. **Result:** risk analysis using the FMEA method shows that the risk of landslide excavation walls in excavation activities ranks highest in road work with a total RPN value of 460.8. Being hit and hit by heavy equipment during excavation activities is the highest risk in Geotextile Installation work, with a total RPN of 405.5, while in Precast Canal Installation work, The risk of being hit by a passing train when marking and staking out is the highest risk with RPN 344.1. **Conclusion:** the results of a review of HIRARC and JSA documents show there are 49 risks consisting of 14 risks in precast channel installation work, 19 risks in geotextile installation work, 16 risks in road bodywork.

Keywords: Risk Identification, Failure Mode Effect Analysis (FMEA), Work Accidents, Risk Control.

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INTRODUCTION

The elevated railway line construction project between Solo Balapan - Kadipiro is one of the government's efforts to increase the frequency of train trips and the safety of train travel and road users so that it can support transportation development and integration between modes of transportation in the city of Surakarta. The Solo Balapan-Kadipiro elevated line project is considered a high risk of danger because it is in direct contact with the highway and is located between residential areas, so it can potentially cause work accidents for employees or workers at the project site. The construction industry is one of the industrial sectors with a fairly high risk of work accidents; this is associated with the unique characteristics of construction projects, different work locations, open and affected by weather, limited implementation time, dynamic, and demands high physical endurance. High, and uses a lot of unskilled labor (Ramdan & Handoko, 2016). Railway bridge construction projects (elevated track), especially on double track (double track), are always large-scale operational, using modern technology, complex structures, high-quality technical standards,

and long duration. For this reason, risk management in a double-track railway development project must be managed effectively to realize objectives, costs, processes, and quality (Munang et al., 2018). According to the Association of Construction Occupational Safety and Health Experts, work accidents in construction service activities currently constitute the largest share of the number of work accidents (Salami, 2015).

Incident accident work could have an impact that lights until raises victim's soul and raises loss in various aspects. Besides the impact on workers, construction work accidents can also negatively impact project performance. Between impact which occur could form increases in project costs, a decrease in project productivity, and even lateness in settlement project. The definition of "risk" cannot be separated from the meaning of "safety" and "occupational health." Here, safety means that there are no unacceptable risks at work, and occupational health means hazards and diseases due to work risks. Moreover, the risk is a combination of an event's probability (rate) and the damage it causes. Most work accidents are caused by two (2) causative factors, namely physical and human factors. Unsafe working conditions are a cause of accidents due to physical factors. In contrast, the human factor is caused by the behavior of workers who do not meet safety requirements because of drowsiness, carelessness, fatigue, and so on. Of the various work accidents, the human factor is the biggest cause (Syakbania & Wahyuningsih, 2017).

Not denied that risk accident is something that has the potential to happen and is quite difficult to eliminate. Risks arise as a result of uncertainty about something profession. The risk could be anticipated and minimized with analysis right. Calculation risk accidents could become an ingredient consideration in minimizing work accidents on implementation project construction, that is, form action preventive measures to address these risks. One method appropriate for analyzing risk on something a series of construction processes is the FMEA method (*Failure Mode and Effects Analysis*) (Hanif & Basuki, 2022). The goal of FMEA is to take action to identify, prioritize, limit, eliminate or reduce failures, starting with those with the highest priority (Budiarto, 2017). FMEA is used during design to prevent failures. It is then used for control before and during ongoing process operations. Identifying risk factors and problems using FMEA can reduce the likelihood of accidents on a construction site. Safety management can also prevent accidents more efficiently than just using checklists (Song et al., 2007). Method this have superiority compared to method other that is because besides evaluation based on levelseverity (*Severity*) and occurrence rate (*Occurrence*), as well could conduct evaluation level detection (*Detection*) based on control design (*design control*) on a project (Ihsan & Nurcahyo, 2022). Method FMEA is something method which designed for:

- a. Identify and understand mode failure, the causes of the failure, and the effects of the system for processing something certain product.
- b. Evaluate risk related to the mode which identified the failure, its effects, and causes, and focus action control.
- c. Identify and implement control measures to resolve that problem. Enough. Are you serious?

Fishbone diagrams (fishbone diagrams) are often called Cause-and-Effect Diagrams or Ishikawa Diagrams, introduced by Dr. Kaoru Ishikawa, a quality control expert from Japan, as one of the seven basic quality tools (7 basic quality tools). The Fishbone diagram is a tool that can identify, investigate, and graphically detail all the causes of a conflict (Kurnianto & Azizah, 2022). . Fishbone diagram has a basic concept where the fishbone diagram is a basic conflict that is placed on the right

side of the image or depends on the structure of the fishbone. Several factors are involved in the fishbone diagram analysis method, namely: 1. Human Factors (Man) 2. Work Methods (Method) 3. Materials 4. Machines (Machine) 5. Environment (Andriani & Ghazian, 2016).

The project that forms the basis of this research is the construction of an *elevated line* between Solo Balapan-Kadipiro phase 1, which is in Surakarta City, to be precise in Banjarsari-Kadipiro Village and Nusukan-Joglo Village, which is divided into three zones, namely zone 1 with a length of 900 m, zone 2 with a length of 200 m, and zone 3 with a length of 550 m. The Solo Balapan-Kadipiro *elevated line* project is considered a high risk of danger because it is in direct contact with the highway and is located between residential areas, so it can potentially cause work accidents for employees or workers at the project site. To know more about risk accidents that could occur, a study was conducted.

METHODS

This research was conducted using qualitative and quantitative methods to obtain information and data related to the analysis using the FMEA method and fishbone diagrams. Data comes from primary data and secondary data. Primary data was obtained from distributing questionnaires, while secondary data was used to support the validity of the data in this study.

1. Risk Identification

Risk variables were identified from literature studies, field observations, hazard identification risk assessment and risk control (HIRARC) documents, and project Job Safety Analysis (JSA) documents. Then proceed with a preliminary questionnaire to obtain validation from respondents regarding whether or not the risk variable is relevant to the factual conditions in the project. Then proceed with the main questionnaire to assess Severity, occurrence rate, and detection rate with the scale shown in Tables 1, 2, and 3.

Table 1. Scale for Occurrence (how often failure occurs)

<i>ranking</i>	<i>Effect</i>	<i>Probability of Failure</i>
1	Rarely	< 1 in 150000
2	A little	1 in 150000
3	Very small	1 in 15000
4	Small	1 in 2000
5	Low	1 in 400
6	Currently	1 in 80
7	High Enough	1 in 20
8	Tall	1 in 8
9	Very high	1 in 3
10	Almost certainly	>1 in 2

Table 2. Scale for Severity (impact)

<i>ranking</i>	Effect	Effect of Severity
1	There is not any	No effect
2	Very small	No injuries, very little financial loss
3	Small	Requires treatment/first aid or minor loss
4	Very low	Requires treatment/first aid and low loss rate
5	Low	Requires treatment/first aid and a moderate level of loss
6	Enough	Requires medical treatment (thus requiring temporary rest) and results in moderate material loss
7	Tall	Requires medical treatment (thus requiring temporary rest), which results in loss of working days and results in large material losses
8	Very high	Resulting in the loss of bodily functions (disability) and resulting in large material losses
9	Dangerous	Resulting in the loss of bodily functions (disability) and resulting in enormous material losses
10	Very dangerous	Causing death and resulting in enormous material losses

Table 3. Scale for Detection (Detection)

<i>ranking</i>	Effect	Possibility of Detection
1	Almost certainly	Almost certain ability to detect cause and failure mode next failure
2	Very high	Very high ability to detect cause and failure mode next failure
3	Tall	High ability to detect cause and failure mode next failure
4	High Enough	Fairly high ability to detect cause and failure mode next failure
5	Enough	Moderate ability to detect the cause of failure and mode next failure
6	Low	Low ability to detect cause and failure mode next failure
7	Very low	Very low ability to detect cause and failure mode next failure
8	Small	Small ability to detect cause and failure mode next failure
9	Very small	Very little ability to detect the cause of failure and mode next failure
10	Almost impossible	No one can detect the cause of failure and mode next failure

2. Analysis Risk

Analysis risk in a study conducted using the method *Failure Mode and Effects Analysis* (FMEA). In method FMEA, the score *risk priority number* (RPN) will be calculated from each accident risk variable that work might happen. The RPN value is obtained from the results multiplication *severity* (S), *Occurrence* (O), and *Detection* (d) appropriate with equalit following.

$$RPN = S \times O \times D$$

The RPN value obtained from the multiplication of S, O, and D will produce the risk level of the job (Zeng et al., 2010). Jobs with the highest RPN values have a level of risk. Is high, henceforth, it will get priority key to taking preventive measures and repair (curative) (Ihsan & Nurcahyo, 2022).

3. Risk Control

According to (Ramli, Soehatman, Djajaningrat, Husjain, Praptono, Risa, Priyadi, 2010), risk control is a step that needs to be carried out according to the results of hazard identification and risk assessment that has been carried out to reduce the level of danger to the safest condition. Risk control determines whether the risk is acceptable or not based on the risk analysis and evaluation results. Control risk is conducted to minimize and avoid potential risks that might happen to something professional. Control risk is this function to reduce the impact generated by variable risk so that it does not generate accident work. Details of risk control in this study were obtained through Interview source person experts in the field. The interview is done once related literature studies causes of risk and appropriate risk control for every profession. Control carried out will focus on work with the highest risk level because the resulting impact is very large, and necessary preventive control measures to reduce the impact.

4. Research Stages

The stages carried out in this research are knowing the background of the problems in the project environment, followed by identifying the problems that occur. The next step is a literature study related to the problem to be studied. The primary data collection was collected through field observations, interviews, and questionnaires (Prawiranegara, 2016). Meanwhile, secondary data was obtained from the implementing contractor. After data collection, which activities are at risk in construction project activities can be seen.

The next stage is to identify the stages of work with a level of risk using the FMEA method. Risk analysis using the FMEA method will produce a Risk Priority Number (RPN) which is used as a reference in determining the order of priority scale. In this study, work accident risk control is focused on the risk with the highest RPN. Determination of the score from FMEA uses a scale of 1-10. The steps for using FMEA are as follows (Mufiq & Huda, 2020)

- a. Determine the value of the level of seriousness or Severity (Severity) due to work accidents.
- b. Determine the Occurance value or the frequency of accidents.
- c. Determine the detection value, the possibility of an error, or the impact of an error.
- d. Calculate RPN (Risk Priority Number) to determine the priority of action to be taken. The Risk Priority Number (RPN) is the multiplication of Severity, Occurrence, and Detection. (RPN = Severity x occurrence x detection).

After getting the RPN value, the subsequent analysis uses a Fishbone diagram for the risk with the highest RPN value. The fishbone diagram method analyzes the causes of accidents (Kurnianto & Azizah, 2022). The analysis diagram that is considered in this study is the human factor (Man), work methods (Method), machine (Machine), and environment (Environment). Details stages of the study could see in Picture 1.

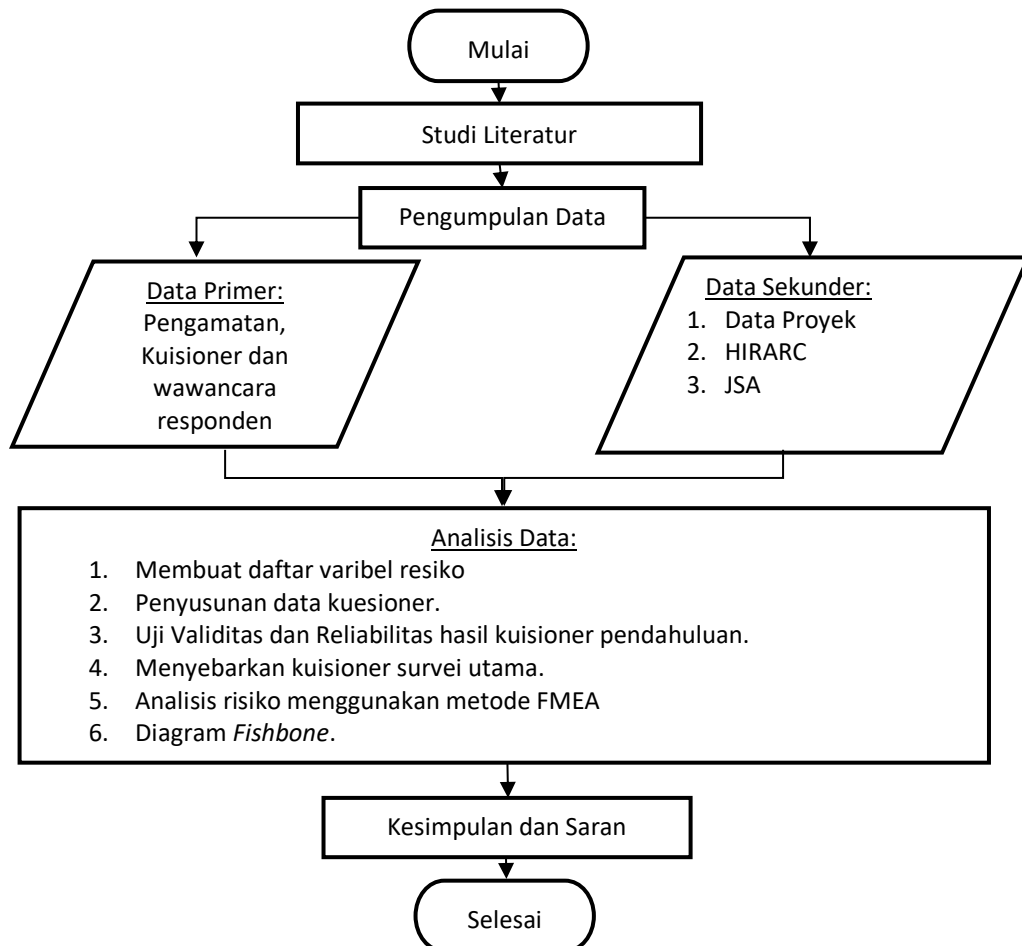


Figure 1. Flowchart

RESULTS AND DISCUSSION

1. Project Profile

The project that forms the basis of this research is the construction of an elevated line between Solo Balapan-Kadipiro phase 1, which is located in Surakarta City, to be precise in Banjarsari-Kadipiro Village and Nusukan-Joglo Village, which is divided into three zones, namely zone 1 with a length of 900 m, zone 2 with a length of 200 m, and zone 3 with a length of 550 m. The total project implementation time is 720 calendar days starting from 16 January 2022-05 December 2023. The project work that is the focus of this research is installing precast channels, geotextiles, and road work.

a. Precast Channel Installation Work

In this project, the installation of box culvert-type precast ducts 100x100 at KM.105+175-KM.105+550 is the most complex work in the work area of PT. Wijaya Karya. This work is located right next to the residents' housing. The installation was carried out by changing the function of the two meters of the main road into a water channel so that the main road is narrowing, which functions as the main access for residents and access roads for project vehicles. In the process, the priority for attention is the movement of heavy equipment and the people nearby so that they do not enter the work area, which can potentially cause a risk of work accidents. The precast duct installation method used in the elevated line construction project between Solo Balapan-Kadipiro uses an excavator lift tool for earth excavation work and the application of precast ducts. Precast channel installation work begins with trenches or excavations with a soil depth of 1.5 meters. The next process is making a working floor or lean concrete with a thickness of 3 cm; after the lean concrete is dry then, proceed with the installation of precast channels taken from the material storage area not far from the precast channel installation location, the channels are then lifted using an excavator with a tie tool. The chain is then installed by making rows of precast channels assisted by two workers on duty to ensure that the precast channels are installed tightly and flatly. In the process, the priority for attention is the movement of heavy equipment because the location for installing precast ducts is on the main access road for residents and the access road for project vehicles, so it has the potential to cause work accidents.

b. Geotextile Installation Work Method

The geotextile installation at this stage is intended to improve the subgrade at KM.105+350-KM.105+475 and KM.106+000-KM.106+075. It is used as a separator at KM.105+125-KM. 105+550 and KM.105+925-KM.106+300. This work is quite safe from the reach of residents because the work is carried out at the excavation site. However, this work is in direct contact with railroad tracks that are still active, so the potential risk of work accidents tends to be more for project workers prone to being hit by trains or buried in material. Geotextile installation is used as a soil improvement and separator in the elevated line construction project between Solo Balapan and Kadipiro. The working method for installing geotextile as a soil improvement begins with sonder testing carried out in the field to determine the carrying capacity of the soil. After the carrying capacity of the soil is known, proceed with excavating the soil. Soil excavation is carried out using excavator lifting equipment with an average digging depth of 2 meters. After excavation of the soil is carried

out, at certain points, namely at km 105+300 – 105+425 and at km 105+875 – 106+075, soil improvement is carried out to increase the carrying capacity of the soil, which has a CBR value of <6% using granular material. Covered with geotextile. Before the material is spread out, the site is cleaned so that the ground surface is flat and clean from sharp objects that can damage the geotextile. Material deployment starts from the initial location of the access in and out of the transport vehicle, which is carried out manually by six workers, and geotextile cutting activities are carried out using a cutter so that the length of the material can be adjusted according to the needs of the field which is then installed transversely and connected using a geotextile sewing machine. Whereas in the method of installing geotextile as a separator, it is done by laying geotextile on top of selected soil which is used as a dividing layer between the tire body construction and sub-ballast by connecting the geotextile layers in an overlapping manner extending 50 cm wide with the aim that water from the upper structure flows sideways and does not enter the landfill because it can affect the stability of the landfill. The geotextile installation work is in direct contact with railroad tracks that are still active, so the potential risk of work accidents tends to be greater for project workers, whether prone to being hit by trains or buried in material.

c. Road Agency Work Method

The road work in phase 1 stretches for 1,275 km, starting from KM 105+075 to 106+350. This work is the riskiest for residents and train travel because it is located near the main access for residents and is in contact with active rails so that many residents cross the project area. In addition, there are lots of heavy equipment that can pose a risk of work accidents. The implementation of road work begins with the protection of existing signaling cables. After protection is carried out, it is continued with determining the excavation elevation according to the planning design drawings; then, excavation is carried out using an excavator according to the depth and width of the excavation. After the excavation, the excavated material is transported by dump truck to the disposal site. The next work is spreading selected soil material which is then carried out by improving the soil using geotextile or by direct backfilling. Then the soil is compacted using a roller vibrator, followed by density testing using a sand cone test. Other work in the road is laying the geotextile separator followed by backfilling with granular material using heavy equipment bulldozers so that compaction is required again using heavy equipment vibrator rollers. This road bodywork has problems or disturbances in the course of work, including environmental and weather conditions, so the amount of heavy equipment used must be as maximum as possible to anticipate setbacks in subsequent work items.

2. Risk Analysis with the FMEA Method

Identification of potential hazards in the precast duct installation work, Geotextile Installation work, and Road Agency Work was obtained through direct field observations and risk observations in the hazard identification risk assessment and risk control (HIRARC) documents and job safety analysis (JSA) documents. The risk variable in this study is obtained from the failure mode, which has the potential to occur in a series of construction work processes in the field. There are 49 risks consisting of 14 risks in precast duct installation work, 19 risks in geotextile

installation work, and 16 risks in road work which have been validated, and details can be seen in table 4.

Table 4. Risk Variables

Variable Code	Hazard Type	Risk Variables
Precast Duct Installation Work		
X1	Physical Hazard	Injured due to inadequate lighting in the installation of precast ducts
X2		There was a flood in the installation of precast ducts
X3	Mechanical Hazard	Injured during the installation of stakes
X4		Falling into a dug hole during excavation
X5		Injured by measuring work tools
X6		Hit by heavy equipment while compacting the subgrade
X7		Mapped into the excavation hole during the compaction of the subgrade
X8		Affected by tool maneuvers during subgrade compaction
X9		The worker was hit by a sharp object (hoe) during <i>lean concrete work</i>
X10		The material crushes the worker during the installation of precast ducts.
X11		Squashed precast duct during precast duct installation
X12		Skin and eye irritation due to splashed cement during <i>lean concrete work</i> .
X13	Ergonomic Hazards	<i>The mixer truck</i> collapsed during <i>lean concrete work</i>
X14		Injured due to damage to the tool during the installation of precast ducts
Geotextile installation work		
X15	Physical Hazard	Landslide in the excavation of land for <i>replacement</i>
X16	Mechanical Hazard	Got hit by a passing train while <i>marking and staking out</i>
X17		Trapped in a dug hole during <i>marking and staking out</i>
X18		Got hit by a passing train tool mobilization
X19		Hit by heavy equipment while <i>stripping the existing soil</i>
X20		Exposed <i>geotextile cutting tool</i>
X21		Scuffs exposed to the material during <i>geotextile installation</i>
X22		Crushed by the material during <i>geotextile installation</i>
X23		Slipped while accessing the <i>geotextile installation work area</i>
X24		<i>geotextile installation</i>
X25		Buried granular material in the drop of material from the <i>dump truck</i> during the spread of granular material
X26		Mapped into the excavation hole during the spread of granular material
X27		Was hit by a <i>dump truck</i> when laying granular material
X28		Was hit by a passing train during compaction of granular material
X29	Chemical Hazard	Breathing problems when <i>stripping existing soil</i>
X30		Respiratory disorders due to dust during compaction of granular material
X31	Ergonomic Hazards	Back injury during <i>geotextile installation</i>
X32		The remaining pieces of <i>geotextile</i> scattered during <i>geotextile installation</i>
X33		a <i>dump truck</i> overturned when the granular material was spread

Road Agency Work		
X34	Physical Hazard	The walls of the excavation collapse during excavation activities
X35	Mechanical Hazard	Got hit by a passing train while <i>marking</i> and <i>staking out</i>
X36		Slipped while accessing the <i>marking work area</i> and <i>staking out</i>
X37		Being hit by a vehicle entering the work site during equipment mobilization
X38		Falling into a dug hole during excavation activity
X39		Being hit and hit by heavy equipment during excavation activities
X40		Hit by a sharp object (<i>cutter</i>) when installing the <i>geotextile</i>
X41		Mapped into the excavation hole during <i>geotextile installation</i>
X42		Buried by soil on land subsidence from <i>a dump truck</i> during a landfill
X43		The collision between heavy equipment during the compaction of embankment soil
X44	Chemical Hazard	Respiratory disorders due to dust during compaction of the embankment
X45		Impaired vision due to dust during compaction of embankment soil
X46	Ergonomic Hazards	Bitten by a venomous/poisonous animal at the time of <i>marking</i>
X47		Heavy equipment overturned during the mobilization of the tool
X48		<i>The dump truck</i> collapsed when the land was piled up
X49		Spilled soil on public roads at the time of landfill

Then after the analysis, the RPN value is obtained from the multiplication of the rank severity (S), Occurrence (O), and Detection (D) values. The questionnaire results determine the S, O, and D numbers associated with the types of work accident risks in installing precast ducts, Geotextile Installation work, and Road Body Works. The average value of the highest-risk respondents for each job is shown in Table 5.

Table 5. RPN Value

NO	Type of work	RISK	S	O	D	RPN
1	The road	The risk of landslides in excavation walls during excavation activities	10	7,2	6,4	460.8
2	Installation of geotextiles	Being hit and hit by heavy equipment during excavation activities	8,8	6,4	7,2	405.5
3	Installation of Precast Channels	Risk of getting hit by a passing train when <i>marking</i> and <i>staking out</i>	9,6	6,4	5,6	344,1

RPN results show that the risk of landslides in excavation activities ranks highest in road work, with a total RPN value of 460.8. Being hit and hit by heavy equipment during excavation activities is the highest risk in Geotextile Installation work, with a total RPN of 405.5, while in Precast Canal Installation work, The risk of being hit by a passing train when marking and staking out is the highest risk with RPN 344.1. Based on observations and interviews, preventive measures have been implemented to anticipate the risk of landslides in the excavation walls, including checking for vibration once a month and providing water barriers or barricades around the excavation. Meanwhile, for the risk of being hit and hit by heavy equipment during excavation activities, several things have been done to anticipate this risk, including before the operator

arrives, checking the validity date of the Operator's License (SIO) and ensuring heavy equipment operators are certified and able to work safely. During the work period, work area security is carried out by monitoring the safety of heavy equipment and worker activities by the flagman, installing warning signs for heavy equipment while working, placing train watchers to control the movement of heavy equipment to reduce the risk of workers colliding or being hit by heavy equipment. Indeed, in road work projects, the priority is the movement of heavy equipment and the people nearby so that they do not enter the work area, which can potentially cause a risk of work accidents. For the work of installing precast ducts, according to observations, a safety line has yet to be installed between the work area and the safety margin of the railroad, which has the potential to cause workers or heavy equipment to be hit by a passing train.

3. Risk Control Efforts

Risk control efforts are carried out to prevent the failure mode from occurring by taking preventive actions to reduce the impact of accident risk. Risk control in this study was obtained from the literature studies and interviews with project parties who know about workplace safety. In this study, risk control efforts were focused on jobs with the highest Risk Priority Number (RPN) rating for each job. RPN results show that the risk of landslides in excavation activities ranks highest in road work, with a total RPN value of 460.8. Being hit and hit by heavy equipment during excavation activities is the highest risk in Geotextile Installation work, with a total RPN of 405.5, while in Precast Canal Installation work, The risk of being hit by a passing train when marking and staking out is the highest risk with RPN 344.1.

Several factors can influence the existence of a failure mode, namely human factors, method factors, equipment factors, and environmental factors. More clearly can be seen in the following Fishbone Diagram:

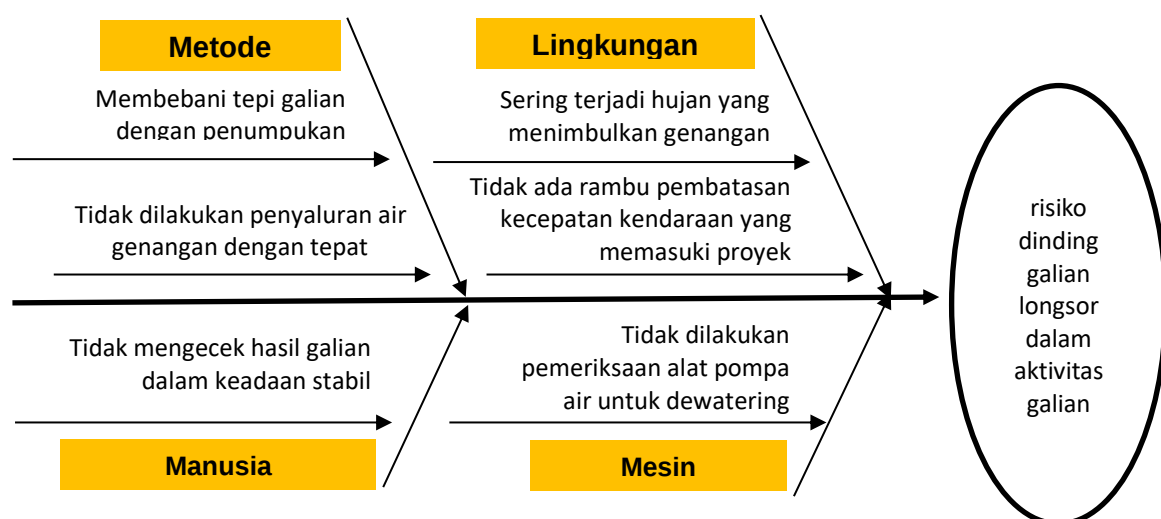


Figure 2. Fishbone Diagram of Landslide Excavation Wall Risk

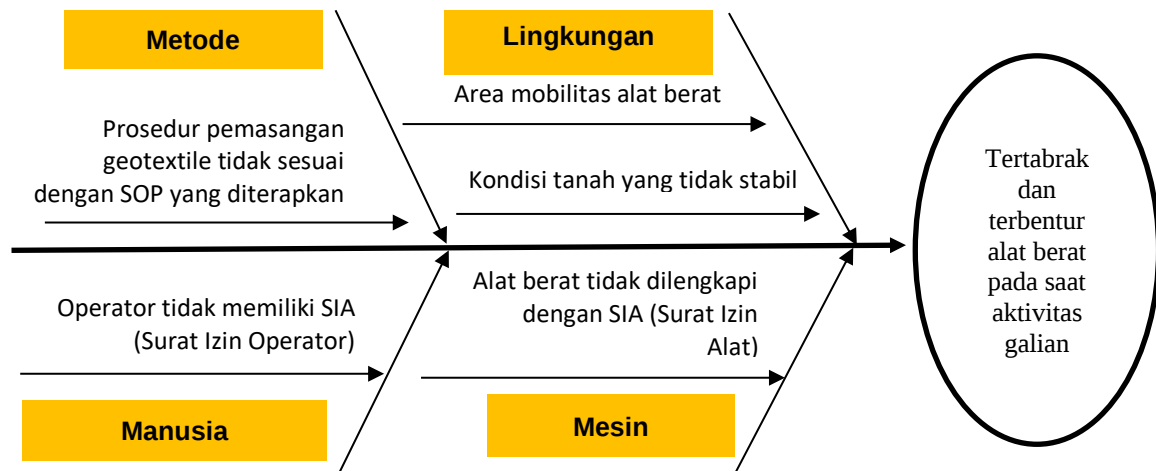


Figure 3. Fishbone diagram of the risk of being hit and hit by heavy equipment during excavation activities

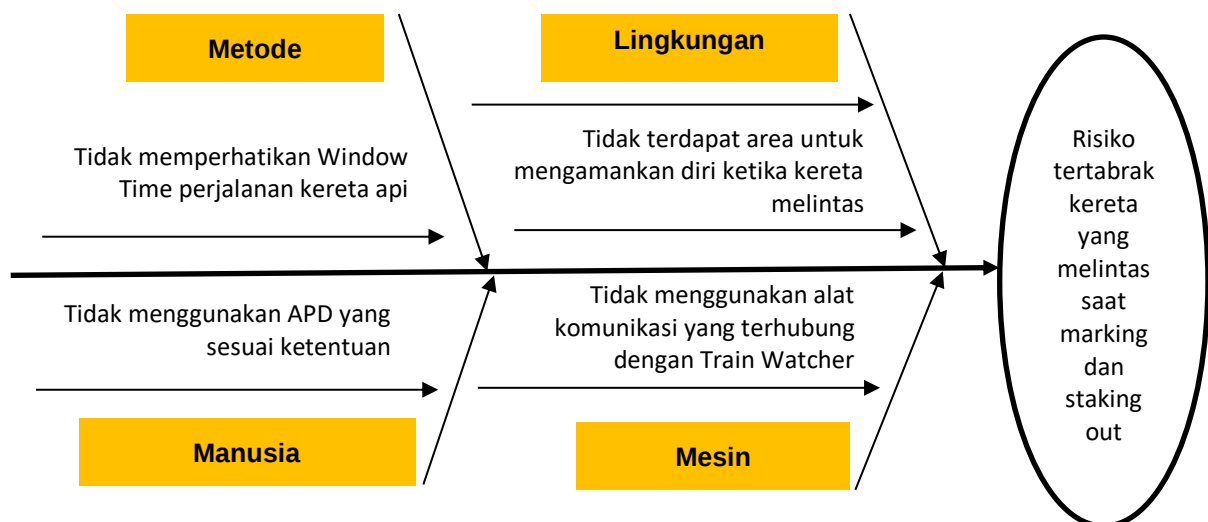


Figure 4. Fishbone diagram Risk of being hit by a passing train when marking and staking out

- a. Suggestions and input for improvements to anticipate the possibility of a landslide excavation wall risk originating from human, method, machine, and environmental factors as follows:

1) Man

The attitude of workers in carrying out excavation activities that have the potential to cause accidents is not checking the excavation results in a stable condition. Suggestions for improvement are to provide training or socialization regarding the dangers caused by excavation activities, and supervisors are expected to always supervise the performance of their subordinates.

2) Machine

The thing that resulted in an accident in this activity was not checking the water pump for dewatering. The suggestion for improvement is to socialize the SOP regarding the routine

inspection of every tool used in excavation activities, including water pumps for dewatering and supervision of the implementation of the SOP.

3) Method

The method used in excavation activities that causes the excavation walls to collapse is to burden the excavation edges with an accumulation of material and not to channel the puddle water properly. Suggestions for improvement are that the project supervisor ensures that there is no accumulation of material on the edges of the excavation, uses landslide monitoring instruments such as an inclinometer installed on the walls of the deep excavation to observe the lateral movement of the excavation walls as well as an early detection tool for landslide movements, and ensures that there are drainage channels around the excavation so that not until there is a high pool of water around the excavation.

4) Environment

Frequent rains that cause puddles and no signs limiting the speed of vehicles entering the project can cause landslides in the excavation walls. Suggestions for improvement during the work period are to secure the work area by installing top speed limit signs in the project area, installing warning signs, such as "Reduce speed now" and "Be careful getting in and out of project vehicles," as well as installing safe limits by using tolo-tolo, safety line, water barrier. After the rain, work continues after inspection because sand slides or landslides may occur.

- b. Suggestions and input for improvements to anticipate the possibility of being hit and hit by heavy equipment during excavation activities originating from human, method, machine, and environmental factors as follows:

1) Man

Operators who do not have an Operator License (SIO) and the attitude of workers in carrying out excavation activities that have the potential to cause accidents are not checking the surrounding environment. The suggestion for improvement is to check and ensure that the operator on duty already has an SIO. Apart from that, they routinely remind workers during toolbox meetings about the importance of checking the environment when carrying out excavation activities and adequate training for operators.

2) Machine

The thing that causes accidents in this activity is the existence of heavy equipment not equipped with an Equipment License (SIA). The suggestion for improvement is to check and ensure that the heavy equipment used is suitable for use and has an SIA.

3) Method

Procedures for installing geotextiles that need to follow the SOPs applied can lead to the possibility of being hit and hit by heavy equipment. The suggestion for improvement is that it is necessary to socialize the SOP and the project supervisor to ensure that all work is carried out following the SOP.

4) Environment

The limited mobility area of heavy equipment and unstable ground conditions can lead to the risk of being hit and hit by heavy equipment. Suggestions for improvement during the work period are to secure the work area by installing safety lines and water barriers. Before

starting work, make sure the work area is safe from possible working conditions that can cause a hazard.

- c. Suggestions and input for improvements to anticipate the possibility of getting hit by a passing train when marking and staking outcomes from human, method, machine, and environmental factors are as follows:

1) Man

Not using appropriate PPE. The improvement suggestion is to require all workers to use complete PPE (helmets, vests, shoes, and safety glasses). Giving punishment to violators can be applied to provide a deterrent effect. Keep a safe distance from the railroad, secure the work area with a safety line, and make sure there are always train watchers on standby when work is in progress.

2) Machine

The thing that resulted in an accident in this activity was not conducting inspection and maintenance of the theodolite and its measuring instruments and not using a communication device connected to the Train Watcher. Suggestions for improvement are periodic maintenance of equipment such as theodolite and its measuring devices and the need to provide the necessary communication equipment for communication monitoring of train operations when working on the track or within the limits of train operation and ensuring that the communication device is active or live.

3) Method

Does not pay attention to the Window Time of train travel. Based on the Regulations of the Directorate of Railway Infrastructure (2019), window time is the interval between train breaks used to benefit the development process and improve the railroad without disrupting the train's journey (DITA AULIA KISTIANY, 2021). The suggestion for improvement is that contractors who require window time submit a work plan and work time requirements and coordinate with the infrastructure operator to estimate the time required. Make sure there are always Train Watcher officers on standby at work.

4) Environment

There is no area to protect yourself when the train passes. Suggestions for improvement during the work period are to secure the work area by installing warning signs, keeping a safe distance, and securing the work area with a safety line.

CONCLUSION

From the results of the research that has been carried out, the following conclusions are obtained: Based on the results of direct observation and the results of a review of HIRARC and JSA documents, there are 49 risks consisting of 14 risks in precast duct installation work, 19 risks in geotextile installation work, 16 risks in road work. Based on the results of risk analysis using the FMEA method, the risk of landslides in excavation activities ranks highest in road work with a total RPN value of 460.8. Being hit and hit by heavy equipment during excavation activities is the highest risk in Geotextile Installation work, with a total RPN of 405.5, while in Precast Canal Installation work, The risk of being hit by a passing train when marking and staking out is the highest risk with RPN 344.1. Efforts to control risks in activities that have the highest RPN for each work, namely in the

form of eliminating failure modes, including by considering the use of landslide monitoring instruments such as inclinometers mounted on excavation walls, socializing SOPs for a routine inspection of tools used, ensuring that there are drainage channels around excavations so that prevent high standing water around the excavation and installation of warning signs to keep a safe distance, and secure the work area with a safety line.

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