Development of Work Breakdown Structure (WBS) for Safety Planning on Tunneling Work Projects Based on Risk

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Abstract. Purpose: Along with advance era and technology, tunnel construction is the alternative infrastructure that can be used as an option, especially in difficult terrain conditions. The tunnel work project is a series of very complex activities. Work activities that are not supervised, causing the risk of these activities neglected. This has become one of the causes of workplace accidents. The risk of work accidents can be prevented by early identification and analysis of potential hazards in each of the activities listed in the project WBS. Therefore, the existence of WBS is needed in presenting a risk assessment, probability and impact arising from the work accidents. The aim of this study is to develop a standardized WBS for safety planning on tunnel construction work based on risk. The standardized WBS will be a main input for identify potential hazard risks and producing risk responses. Methodology: The method that will be used in this research is a qualitative approach with a survey and deep interview to experts. Results: The results of this study are standardized WBS, potential hazard risks and the developed of WBS standard for safety planning, as a step to prevent work accidents in tunneling work projects. Applications/Originality/Value: The implementation of this research is for the contractors who are required to make safety plan, especially in tunneling work projects.

1. Introduction

Infrastructure development in Indonesia has been evolving fast; amongst those development is transportation, which becomes government’s strategy to enhance economic growth and distribution. The progress and quality of transportation infrastructure, such as roads and railways are very important because it is one of the measurements of effective and efficient moving goods and services. The rapid development of information technology affects the innovation and motivation to also escalate infrastructure development, especially with difficult condition such as limited space and high cost. One alternative to develop infrastructure is building tunnel, especially for transportation infrastructure in the form of road and train traffic tunnels.

Tunnel is not a new thing in Indonesia. Tunnels have been built in Indonesia since the beginning of the 19th century during the Dutch colonial era, such as the 260-meter-long Notog Railway Tunnel located in Banyumas Regency, Central Java. In addition, tunnels can also be found in several underground mining exploitation material sites spread in Indonesia. According to [1], tunnels are one of the future transportation infrastructure alternatives that serve to shorten travel time. In addition, according to [2], road tunnels are very effective in addressing traffic congestion problems and reducing vertical alignment. Indonesia’s topography which...
has many mountainous contours and geological conditions that are rich in mineral mines will make tunnel constructions more thriving. In its implementation, the tunnel project involves a series of complex work activities and requires careful construction which needs involvement of various scientific disciplines, such as mechanical soil, geology, hydraulics, mechanical engineering, concrete science, etc. Because of its complexity, the success of a project is strongly affected by the project definition stage. This is the main factor that affects project failure.

Ministry of Public Works and Housing (PUPR) states that data on the proportion of work accidents in Indonesia for construction sector is the largest contributor along with manufacturing industry by 32% which includes all types of projects such as buildings, roads, bridges, tunnels, irrigation, dams, etc. This is different from the transportation sector (9%), forestry (4%) and mining (2%). In addition, the International Labor Organization [3] states that there are 6000 cases of fatal work accidents occurring every day. For every 100,000 workers there are 20 victims of work accidents with fatal consequences happening in Indonesia. In developing countries, losses due to work accidents are four times higher than those in industrialized countries at US$ 1.25 trillion, equivalent to 4% of the Gross National Product (GNP). Referring to the data from Manpower Social Security Organizing Agency (BPJS), the biggest contributor of work accident numbers nationally is occupational accidents in the construction sector. There are 101,367 work accidents cases recorded in 2016 (until November) with 2,382 people died, another 110,285 accident affects people in 2015 with 2,375 people died. Total of 123,000 work accident cases happen in 2017 with claim value of more than Rp971 billion. This value climbs up from 2016 with total claim value of Rp792 billion [4].

According to King and Hudson (1985) about the challenges of occupational safety and health problems in construction development projects in Indonesia (developing countries), the death rate is three times higher compared to the ones in developed countries. From the various activities of construction projects implementation, the most dangerous works are those that involve elevation and excavated works. In both types of work, work accidents that occur tend to be serious and often resulted in permanent disability or death. Most work in tunnel construction is earthwork, which include excavation work.

Work accidents can be reduced if project activities can be well planned and work packages can be arranged at the suitable levels and tiers based on standardized WBS. Each level of WBS brings to a more complex level; which are risky activities and have impact on safety plans. Potential risk of each action step that has been arranged in the WBS standard will be simpler to be identified, thus risk mitigation can be mapped from existing risk sources for the project implementation so it is important to develop a risk-based WBS standard that can be implementer for safety planning so that it is expected to achieve a goal that can be utilized as a guideline for construction deployment [5]. The questions of this research are: How is the WBS standard for tunneling work projects? (RQ.1) What are the risk factors that affect safety performance of tunneling work projects? (RQ.2) How is the risk-based development WBS for safety planning on tunneling work projects? (RQ.3)

2. Literature Review

2.1. Tunnel

Tunnels are horizontal or slightly sloping open holes made underground, mountains, rivers, seas, industrial areas, even densely populated settlements [6]. Tunnels that are made to take underground minerals are known as mine tunnels. Tunnels that are made to penetrate natural obstacles or human-made obstacles are called civil tunnels. Tunnel construction consists of two main stages; they are the excavation stage including the construction and manufacturing stage of tunnel structures and equipment supporting tunnel works such as the installation of ventilation, lighting, security and other systems [7]. According to the International Tunneling Association (ITA, 2009) there are three types of tunnel construction methods based on the
technology used; they are conventional methods, mechanical methods and cut and cover methods. Underground development needs firm commitments and obligation to comprehensive and complicated procedures. Underground development demands high management expertise to address complex and challenging probability. Lack of understanding of several significant factors, such as the unique detachment features and ensuing interrelated complexities, can increase the difficulties of underground construction [2].

2.2. Work Breakdown Structure

Work Breakdown Structure (WBS) is a hierarchical division of work that is deliverable-oriented to be done by the project executor in order to achieve project goals and required achievement. Achievement in question is a unique output, result, or capability to display the services that have to be achieved to complete the process, phase, or project. WBS often narrowly used as reference to external achievement, which are subjected to sponsor or customer of the project’s approval [8]. Making WBS itself is a system of describing project deliverables and work into individual components which translated into a list that is top down and ordered explains the components that must be constructed and its associations. Each WBS level derivative represents an increasingly detailed definition of the project [9].

2.3. Risk Management

Risk management for program is a methodological process of identifying, analyzing, responding to, and controlling risks that may occur during a program implementation. Risk management is related with the goal to increase the possibility and/or positive risk impacts as well as reducing the possibility and/or negative risk impacts to optimize the success of a program [10–12]. Risk management is a crucial part of the decision-making process in construction project management that will affect scope, time, integration, quality, human resources, cost, communications and project procurement. Therefore, in order to do risk identification, WBS must be categorized based on work packages, methods / designs, activities, material resources, equipment, and labor and the environment so that risk events can be identified that can affect safety performance objectives. Creating stratified risk management with RBS can improve uncertainty and probabilities identification in the future projects [13–16].

2.4. Safety Planning

Safety Planning is a pragmatic safety designing that can help corporates avoid potential threat and control those threats in the best way when they are in those dangerous conditions. Health Safety Environment Plan (HSE Plan) should not only consider hazardous conditions for human but also consider the condition of factors from environment, flora and fauna that exist in the project area surroundings [17–21]. At construction sites physical trauma and accidents can occur, for example people who fall from certain height and crash into materials or equipment. One of possible roots of work accidents are negligence of workers and also undisciplined. Accidental anticipation for workers in the project area is implemented to raise understanding in preventing workplace danger management strategies for construction [13].

In a safety plan, the document standard that is made is safety issues of work operations documents which include: danger identification, risk assessment and mitigation steps and circumstances that must be met to keep the level of safety [14]. The Safety Plan document refers to the Regulation of the Minister of Public Works No.05 / PRT / M / 2014 concerning Guidelines for the Occupational Safety and Health System (SMK3) in the Field of Public Works. The safety planning document in the regulation is known as the Contract Work Safety and Health Plan (RK3K).
3. Method

To answer the research objectives, this research used a qualitative approach. Data collection was obtained by survey and interview methods to 5 professionals that have the expertise in tunnel construction with more than 10 years of experience with structured questionnaires. The sequence of this research can be seen in Figure 1.

The stages of this study began with the data collection of tunnel construction projects, expert validation of WBS Tunnel Construction Work, Expert Validation regarding risk factors that affect safety performance, pilot surveys, respondent questionnaires, expert validation regarding the analysis results of the calculation of respondents, and final validation of overall results.

In this study, to get the WBS variable Tunnel Construction Work the authors conducted an archive analysis of 4 similar tunnel construction project data. The analysis results were then validated to 5 experts, which finally resulted in WBS variable tunnel construction work consisting of 7 clusters of work, 26 types of work, and 79 work packages. Meanwhile to get the variable, authors identified the potential risks that affect safety performance of variable analysis of previous similar studies then validated to experts.
4. Result and Discussion

4.1. To answer Research Question 1

From literature review about tunnel construction technical guidance and 4 (four) previous project information, it is concluded that tunnel construction work has 7 cluster of work, they are preparation, earthwork, support and protection work, concrete work, drilling and grouting work, drainage work, and miscellaneous work. The WBS of each categories can be seen in Figure 2.

![Figure 2: Work Breakdown Structure Standard on Tunneling Work Projects Diagram](image)

4.2. To answer Research Question 2

Once the WBS standard is attained, the next step is identifying the risks that affect the safety performance of tunnel construction works based on several categories. The risk variables in this research are explained in Table 1.

| Category                        | Risk that Influence Safety Performance Variables                                                                 |
|---------------------------------|---------------------------------------------------------------------------------------------------------------|
| Work Package                    | X.1 Changes in design and scope of work<br> X.2 Subcontractor productivity is not achieved<br> X.3 Acceleration (crashing does not pay attention to safety procedures)<br> X.4 Job packages changes (new job)<br> X.5 Insufficient geological and geotechnical information and data |
| Design/Method Alternative       | X.6 Safety plan is not congruence with the planned method<br> X.7 Errors in planning implementation method / not in accordance with the field condition<br> X.8 Errors in calculating work volume<br> X.9 Not doing work scheduling<br> X.10 Errors in construction method |
| Activity                        | X.11 The planned job sequence is not risk-based<br> X.12 There are activities that are not planned during project planning<br> X.13 Installation is not according to specifications or drawing plan |
X.14 Planning errors in defining complete project activities
X.15 Respiratory disorder due to natural gas
X.16 Respiratory disorder due to smoke blasting
X.17 Eye irritation due to smoke blasting and dust
X.18 Workers are electrocuted by pumping machine cables
X.19 Workers fall into the pit
X.20 Workers are splashed or doused by concrete / shotcrete
X.21 Unsteady steel support
X.22 The concrete pump pipe is broken
X.23 Worker’s feet are hit by the hoe
X.24 Skidded / slipped
X.25 Workers are exposed to / sprayed by herbicide solutions
X.26 Workers are buried in the ruins of the tunnel wall
X.27 Exposed (barometric pressure, temperature, radiation, sound, vibration, light, etc.)
X.28 Accidents during heavy equipment mobilization
X.29 Ready mix from concrete pump spilled / splattered to workers

Material Resources
X.30 Leftover material that cannot be controlled (many)
X.31 Material testing does not comply with the planned procedure
X.32 Material quality does not meet specifications
X.33 The material specifications used are not appropriate
X.34 Lack of control over project waste / material waste
X.35 Lack of control over the use of hazardous materials
X.36 Unavailability of explosive warehouse
X.37 Explosive materials are not safely keep
X.38 Mobilization and demobilization of explosives is not in accordance with procedures
X.39 Skin disease due to exposure to hazardous materials
X.40 Harmful substances are absorbed through breathing / skin into the body

Equipment Resources
X.41 There is no quality control for tools
X.42 Low tool capacity
X.43 Low tool quality
X.44 The equipment usage is not in congruence with the prepared execution method
X.45 Equipment specification is not according to plan
X.46 Formwork collapse
X.47 Tools crash upon surrounding workers / facilities
X.48 Exposed to dump truck maneuvers
X.49 Exposed to swing excavator
X.50 The drill tool collapsed and tilted

Labor Resources
X.51 There is no training for workers
X.52 Low educational background of workers
X.53 The use of labor does not match expertise
X.54 No scheduling of workforce
X.55 Lack of teamwork
X.56 Limitations of experienced staff and typical building work method specialists
X.57 The number of workers is not according to plan
X.58 Low productivity of workers
X.59 Bad behaviour of workers
X.60 Failure on estimating labor productivity required
X.61 Workers are not ready for the implementation of new methods
X.62 Low quality of workers
X.63 Unclear tasks and authority
X.64 Too much overtime

Environmental Factor
X.65 Unavailability of Work Instruction
X.66 No ongoing meeting toolbox meetings
X.67 No evaluation of safety plan
X.68 Weather conditions are out of the estimation
X.69 The subsurface geological and geotechnical surroundings are not as outlined
X.70 Natural disasters
X.71 Contaminated underground water
X.72 Landslide
X.73 Tunnel wall collapse
X.74 Dirty / slippery road due to scattered soil

Any possible dangerous risks in tunnel construction collected from literature studies were then identified, verified, clarified and validated by professionals to be made as content and constructs. Professionals were requested to give their opinion with the risk factors, whether they agree or disagree as well as their input on every single risk factors, impacts and causes. On top of that, professionals were asked to give list of additional risk factors. Once the feasibility and impact were decided, the score of each risk factor can be calculated with the following method:

\[ R = P \times I \]  

Where \( R \) = Risk factor, \( P \) = Probability, and \( I \) = impact. The risk level matrix, also called probability and impact matrix, can be seen in Table 2.

| Probability | Impact | Risk Value |
|-------------|--------|------------|
| Very High   | 0.90   | 0.18       |
| High        | 0.70   | 0.14       |
| Moderate    | 0.50   | 0.10       |
| Low         | 0.30   | 0.06       |
| Very Low    | 0.10   | 0.02       |
| Very Low    | 0.05   | 0.01       |

The validated variable was then calculated to see the risk value to determine the risk defined as 'high' category based on the PMBOK 6th Edition assessment matrix through the opinions of 30 respondents and expert validation. From these results there are risks that fall into the category of low risk level, moderate risk level, and high-risk level.
4.3. To answer Research Question 3
The results of risk events that fall into the ‘high’ category were validated by experts, then was discussed with experts regarding the causes and impacts of each risk. After causes and impacts were discussed, the authors then conducted a discussion related to the risk response, which is the appropriate preventive and corrective action for each of these risks, as well as their categorization with experts.

According to the experts, risk response recommendations can be incorporated into several alternative actions for the development of WBS, which are add to management item, add to the other WBS, add to the relevant WBS, add to the job qualifications, and changes to the WBS coefficient. These alternative actions become additional activities in the WBS Tunnel Construction Works standard, therefore it develops risk based WBS standards. The results of this development can be used as guideline in the preparation of safety plan documents in accordance with activity stages that have been defined. The safety plan document uses the format as stated in Minister of Public Works Regulation No.05 / PRT / M / 2014 with the addition of a column to the list of work packages, activities and risk control.

5. Conclusion
According to the result and discussion, it can be concluded WBS standard for Tunnel Construction works divided into 6 level as follows, Level.1: Project Name, Level.2: Cluster of work, Level.3: Type or work, Level.4: Work Package, Level.5: Activity and Level.6: Resource. Design/method alternative as a part to define what activity and resource required to finish the work package. Analysis of the risk-effect produces risks that fall into the category of low risk level, moderate risk level, and high-risk level. The results of risk events that fall into the ‘high’ category are identified based on the causes and impacts of those risks. Then the authors conduct a discussion related to the risk response, which is the appropriate preventive and corrective action for each risk, as well as its categorization with the experts. These alternative actions become additional activities in the WBS Tunnel Construction Works standard so as to result in the development of risk-based WBS standards. The results of the development can be used as a guideline in the preparation of safety plan documents using a modified format from Minister of Public Works Regulation No. 05 / PRT / M / 2014.

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