IDENTIFICATION OF CONSTRUCTION SAFETY RISKS FOR IRRIGATION NETWORK PROJECT BASED ON THE WORK BREAKDOWN STRUCTURE (WBS) TO IMPROVE CONSTRUCTION SAFETY PERFORMANCE

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ABSTRACT

The construction sector in Indonesia faces a high risk of occupational accidents, particularly in irrigation network projects. This study develops a standardized Work Breakdown Structure (WBS) for irrigation projects to improve safety performance. The WBS standard, detailed into 177 activities across five levels, enables precise identification of safety risks during project planning. Utilizing expert validation through the Delphi Method, 708 risk variables were identified, with 25 dominant risks grouped into three main categories: heavy equipment-related accidents (material lifting failures and traffic collisions) and electric shocks. This framework enhances the implementation of preventive measures and aligns safety management systems with construction activities. Findings reveal that material lifting failures with mobile cranes, traffic-related heavy equipment accidents, and electric shocks are the most significant risks. Integrating WBS-based safety planning during pre-construction improves project safety performance, reduces costs, and enhances sustainability. This research highlights the critical need for comprehensive safety strategies tailored to irrigation projects.

***Keywords**: Work Breakdown Structure, construction safety, irrigation networks, risk management, safety performance.*

INTRODUCTION

Agriculture in Indonesia contributes significantly to the national economy, with the agriculture, forestry, and fisheries sectors always in the top 4 largest contributors to GDP in 2018-2021, reaching an average of 13% (Statistics Indonesia, 2022). Irrigation plays an important role in increasing agricultural productivity by providing, regulating, and disposing of water (Ministry of State Secretariat of the Republic of Indonesia, 2006). In 2020-2022, the Ministry of Public Works and Housing of the Republic of Indonesia developed 121,411 ha of new irrigation networks and rehabilitated 826,530 ha, with a target until 2024 to include the development of 500,000 ha and the rehabilitation of 2,000,000 ha. The success of irrigation projects depends on the design, systematic planning, and implementation of the Work Breakdown Structure (WBS) as the basis for planning (Tamara, 2019). WBS divides the project scope into controlled activities to the lowest level, which is vulnerable to risk. Active risk management has a positive impact on occupational safety, improving safety behavior and performance (Fernandez-Muniz, Montes-Peon, & Vasquez-Ordas, 2014)

The number of occupational accidents in Indonesia has been on the rise since 2015, with 234,370 reported victims in 2021—the highest figure in the last 16 years. Specifically, in the construction sector, accident cases increased from 114,000 in 2019 to 177,000 in 2020. Notably, 64.4% of these accidents occurred within the workplace, highlighting that the workplace is a particularly high-risk area for accidents (Ministry of Manpower of the Republic of Indonesia, 2022).

Construction accidents can significantly impact the sustainability of projects, companies, and global competitiveness. At the project level, accidents can lead to delays in completion and increase costs associated with accident management and environmental restoration (Manik, et al., 2021). On a global scale, the estimated cost of workplace accidents is around USD 2.8 trillion, which accounts for approximately 4% of the world's GDP (International Labour Organization, 2011).

According to the pyramid theory, for every significant work accident that results in an injury, there are 29 minor injuries and 300 near misses without injury (Hinze, Pedersen, & Fredley, 1998). A near miss is defined as a dangerous situation that almost leads to a serious accident but ultimately stops before causing a significant impact (Andriulo & Gnoni, 2014). Near misses occur due to unsafe behaviors and conditions, but various factors prevent them from escalating into serious accidents (Saleh, Saltmarsh, Favaro, & Brevault, 2013).

More attention should be paid to safety planning at the preconstruction stage to improve safety management more effectively (Mesaros, Spisakova, & Mackova, 2019). Incorporating safety into the overall project plan at the beginning of the project has a strong positive effect on occupational safety performance (Veteto, 1994). Therefore, to be able to reduce the rate of construction accidents in irrigation canal work, it is necessary to identify accident risks based on standardized WBS. The purpose of this study is to make a standard WBS for irrigation network work and identify risky activities including the level of risk of construction accidents.

Irrigation Network

An irrigation network is a channel, building, and its complementary buildings which are a unit necessary for the supply, distribution, provision, use, and disposal of irrigation water (Ministry of State Secretariat of the Republic of Indonesia, 2006). There are four main elements, namely the main building for water intake, the carrier network that flows water to the tertiary plots, the tertiary plots that divide the water to the rice fields and manage the excess water and the sewer system that drains the excess water into rivers or natural canals (Ministry of Public Works and Housing of the Republic of Indonesia, 2013).

Work Breakdown Structure (WBS)

Work Breakdown Structure (WBS) is a hierarchical decomposition of the scope of project work to achieve the necessary objectives and deliverables (Project Management Institute, 2017). WBS is a frame of reference for project elements, schedules, and estimates, and supports the integration of plans related to time, resources, and quality (Rad, 1999). The process of creating a WBS divides deliverables and project work into smaller, more manageable components, providing a clear framework for implementation (Project Management Institute, 2017).

The approach followed by the project team in terms of WBS development ranges from the reuse of previous WBS with some changes, to the progressive breakdown of the work required for the project, to the development of deliverable-based WBS with a focus on the core functionality of the final product (van Tonder & Bekker, 2002).

Construction Safety Risks

The Health and Safety Executive (HSE) defines 'safety risk' as: "the likelihood that a person may be harmed or suffer adverse health effects if exposed to harm" (Bortey, Edwards, Roberts, & Rillie, 2022). This is because construction is one of the most dynamic and dangerous industries. Frequent work team rotations, exposure to weather conditions, a high proportion of unskilled workers, and uncertainty are some of the unique factors of construction sites (James, Ikuma, Nahmens, & Aghazadeh, 2012).

Construction safety is all engineering activities that support construction work in realizing the fulfillment of security, safety, health, and sustainability standards that ensure the safety of construction engineering, labor safety and health, public safety, and the environment. The fulfillment of security, safety, health, and sustainability standards in question is by guaranteeing

(Ministry of Public Works and Housing of the Republic of Indonesia, 2021) :

a) Construction Engineering Safety: Safety targets or objects consist of buildings and/or construction assets, and/or equipment and materials intended to prevent construction accidents in the form of construction engineering accidents.
b) Occupational Safety and Health: Safety targets or objects consist of owners/employers, construction workers, suppliers, guests, and sub-providers of services aimed at preventing construction accidents in the form of work accidents and occupational diseases.
c) Public Safety: Safety targets or objects consist of the community around the project and the exposed community which is aimed at preventing construction accidents in the form of accidents to the community.
d) Environmental Safety: Safety targets or objects consist of the work environment, the environment affected by the project, the natural environment, and the built environment which are aimed at preventing construction accidents in the form of environmental accidents.

Construction Safety

Safety management can be defined as the process of realizing a specific safety function, and a safety management system is generally defined as management procedures, elements and activities aimed at improving safety performance and within an organization (Li & Guldenmund, 2018). Poor safety management can increase the risk of construction project failure, making it important for project managers (Zhu, Yuan, Shao, Qiuhu, Zhang, & Wang, 2020). In Indonesia, the Construction Safety Management System is regulated by the Regulation of the Minister of Public Works and Housing Number 10 of 2021 on Construction Safety Management System Guidelines to ensure safety in the implementation of construction. Effective implementation of the Construction Safety Management System can accelerate project schedules, reduce costs, and increase ROI, company reputation, and project quality (McGraw Hill Construction, 2013).

Construction safety management systems have shifted from a rules-based prescriptive approach to a performance-based approach, where companies are responsible for achieving safety goals for all stakeholders (Melagoda & Rowlinson, 2022). The implementation of the Construction Safety Management System in Indonesia must meet Security, Safety, Health, and Sustainability standards (Ministry of Public Works and Housing of the Republic of Indonesia, 2021)

METHODS

This research uses a qualitative approach with the strategies used are archival analysis and historical data as well as surveys. The stages in this study are shown in Figure 1 below.

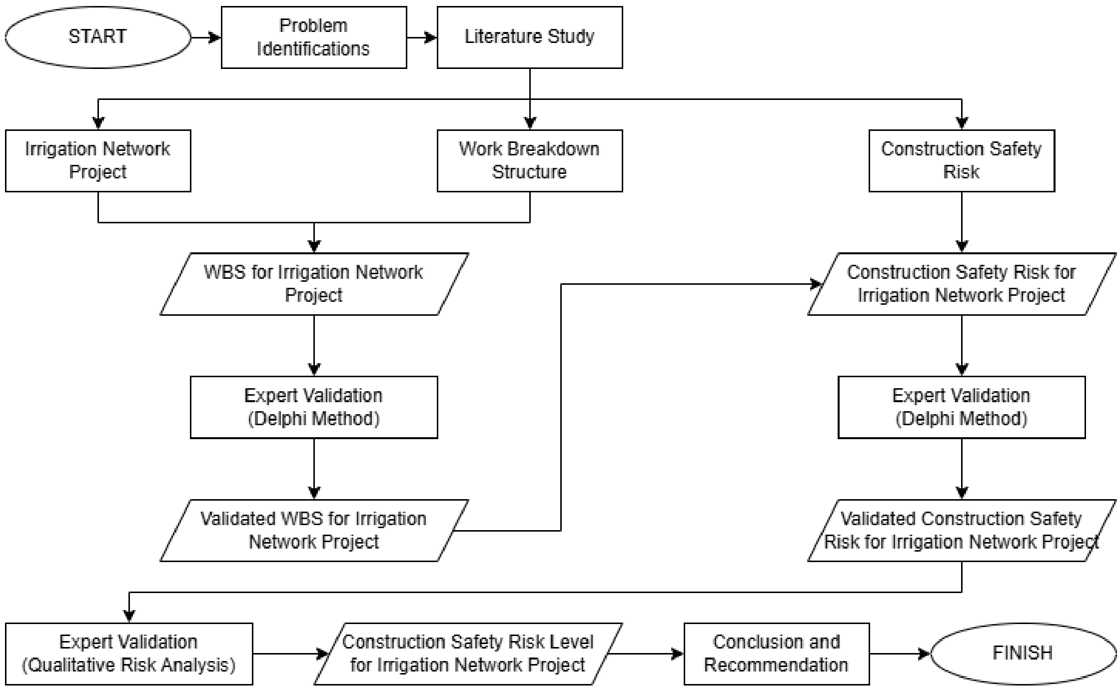

Figure 1 Research Flow Chart
Source: Processed by the author

This study uses literature studies to collect benchmarking data from the independent variables studied. After obtaining the research benchmarking variables from the results of the literature study, then validation is carried out to experts in 3 stages with the following explanation:

a) Phase 1 Data Collection: Carried out to find out whether the variables that have been compiled are activity variables in the WBS of Irrigation Canal Work. The validation process of these experts uses the Delphi Method. This method is carried out to collect expert opinions on activity variables in irrigation canal work to reach a consensus. Activity variables can be clarified and assessed as accurate if they reach the approval of at least 3 experts.

b) Phase 2 Data Collection: Carried out to find out whether the variables that have been compiled are WBS-based construction safety risk variables in Irrigation Canal Work. The validation process of these experts uses the Delphi Method. This method is carried out to collect expert opinions on activity variables in irrigation canal work to reach a consensus. Activity variables can be clarified and assessed as accurate if they reach the approval of at least 3 experts.

c) Phase 3 Data Collection: Carried out to determine the level of construction safety risk based on WBS-based construction safety risk variables that have been validated by experts. The validation process of this expert uses a qualitative risk analysis method. This analysis was carried out to find out the level of risk with a high level of priority and reduce uncertainty. The reference for calculating this risk factor is to use the probability and impact matrix as shown in Table 1 below.

Table 1 Frequency and Impact Matrix

FREQUENCY	IMPACT				
	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Source: Ministry of Public Works and Housing of the Republic of Indonesia (2021)

Based on the matrix above, the range of values for determining risk rating is:

- Low Risk : 1 - 4
- Medium Risk : 5 - 12
- High Risk : 15 - 25

RESULT AND DISCUSSION

Work Breakdown Structure (WBS) for the Irrigation Network Project

The discussion and validation process involved five experts who each have a minimum of 10 years of experience in irrigation network construction management. These experts evaluated and validated the activity variables in the Irrigation Network Work Breakdown Structure (WBS) Standard using the Delphi method. Any variables that were not approved will be removed, and activities may be added or rearranged.

The validated WBS Standard comprises five levels of decomposition: Level 1 (Project Name), Level 2 (Work Cluster), Level 3 (Work Type), Level 4 (Work Package), and Level 5 (Activities), as well as alternative methods. Specifically, it includes 1 Project Name, 8 Work Clusters, 26 Work Types, 67 Work Packages, and 177 Activities. Figure 2 provides examples of validated WBS standards.

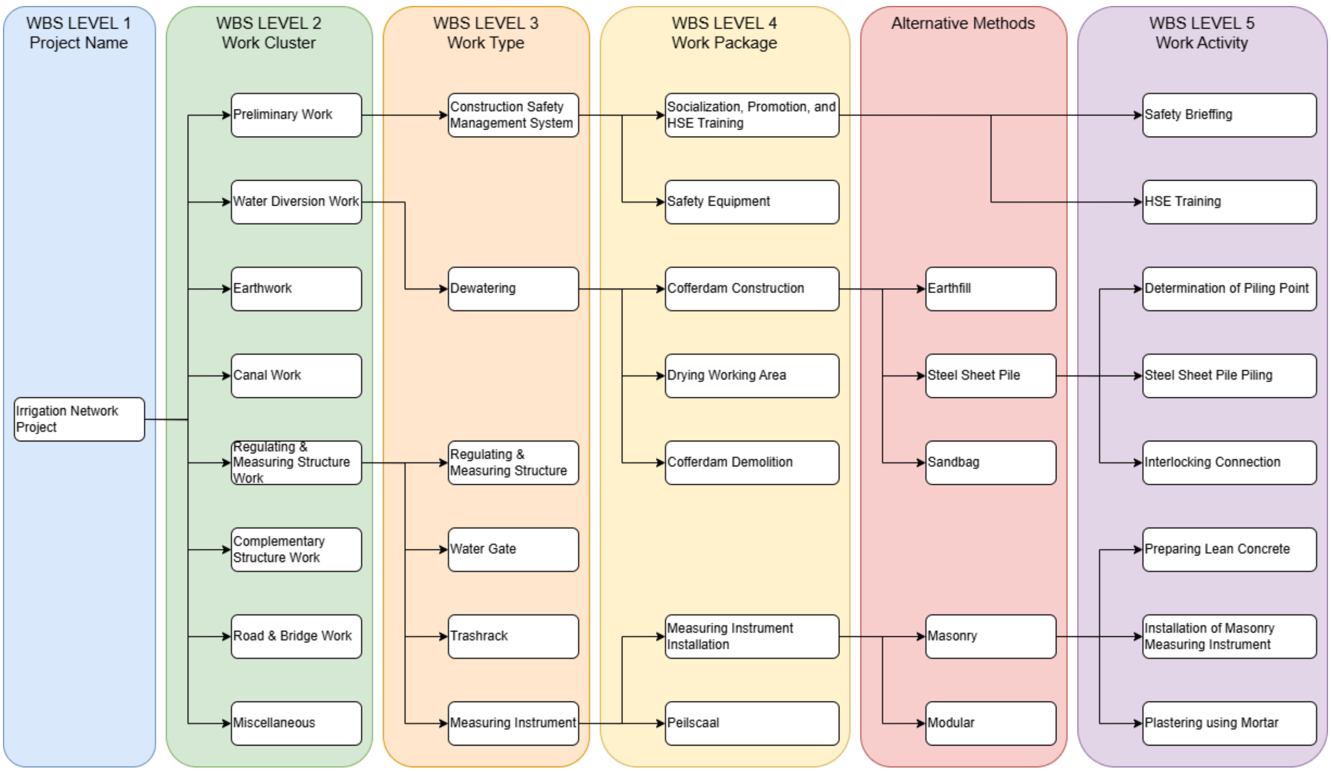

Figure 2 Results of Expert Validation on the WBS Standard for Irrigation Network Projects
Source: Processed by the author

Currently, most irrigation network projects, particularly those managed by the central government authority (irrigation areas larger than 3000 hectares), aim to upgrade to technical irrigation systems. This initiative is supported by the Ministry of Public Works and Public Housing (2013) which indicates that technical irrigation is more advanced and better suited for most irrigation developments in Indonesia.

A key requirement for classifying an irrigation network as a technical irrigation system is the presence of regulating and measuring structures. These structures are essential for effectively regulating and measuring water discharge (Ministry of Public Works and Housing of the Republic of Indonesia, 2013). Therefore, breaking down the work items related to Regulating and Measuring Structures in the Work Breakdown Structure (WBS) Standard is crucial, ensuring that these structures are constructed according to the established standards.

Additionally, the irrigation network projects necessitate a dry work site. Consequently, water diversion or dewatering processes have been included in the WBS Standard for Irrigation Network Project. The dewatering method will depend on the diverted water, namely, groundwater or surface water (Asiyanto, 2006). Expert validation has confirmed that dewatering methods differ based on whether surface or subsurface water is being addressed.

One effective method for dewatering in irrigation network projects is using cofferdams. These cofferdams can be earthfills, steel sheet piles (SSP), or sandbag barriers. This variation in methods leads to differing construction safety risks, particularly when dewatering subsurface water compared to surface water.

Construction Safety Risk for the Irrigation Network Project

The discussion and validation process involved five experts who each have a minimum of 10 years of experience in irrigation network construction safety. These experts evaluated and validated the activity variables in the Irrigation Network Project Construction Safety Risk based on the validated Irrigation Network Project WBS using the Delphi Method. Any variables that were not approved will be removed, and activities may be added or rearranged.

In this study, 708 risk factor variables that affect construction safety performance in irrigation network work were validated, of which 25 were the dominant risk factors in irrigation network work. The 25 dominant risk factors in irrigation network work that have been sorted are shown in Table 2 below.

Table 2 Highest Construction Safety Risk Level for Irrigation Network Project

WBS LEVEL 4 (Work Package)	Alternative Methods	WBS LEVEL 5 (Work Activity)	Variables	Risk	Risk Value	Risk Level
Soil Disposing to Disposal Area		Transporting Excavated Soil to Disposal Area	X.2.277	Collision between vehicles	15,84	HIGH
Mobilization Program		Material Mobilization	X.2.4	Hit by another vehicle while mobilizing materials	15,84	HIGH
Canal Construction using Precast Concrete	Precast Concrete	Precast Canal Installation	X.2.299	Workers below hit by precast materials	15,36	HIGH
Culvert Construction	Precast Concrete	Culvert Installation	X.2.482	Workers below hit by precast materials	15,36	HIGH
Existing Utilities and Services Relocation Work		PLN Utility Relocation	X.2.61	Worker electrocuted	15,36	HIGH
Lift Gate Installation		Lift Gate Installation	X.2.349	Worker electrocuted	15,12	HIGH
Steel Sluice Gate Installation		Steel Sluice Gate Installation	X.2.358	Worker electrocuted	15,12	HIGH
Romijn Gate Installation		Romijn Gate Installation	X.2.368	Worker electrocuted	15,12	HIGH

WBS LEVEL 4 (Work Package)	Alternative Methods	WBS LEVEL 5 (Work Activity)	Variables	Risk	Risk Value	Risk Level
Trash Rack Installation		Trash Rack Installation	X.2.375	Workers below hit by steel materials	15,12	HIGH
Trash Rack Installation		Trash Rack Installation	X.2.377	Worker electrocuted	15,12	HIGH
Soil Disposing to Stockpile		Transporting Excavated Soil to Stockpile	X.2.271	Collision between vehicles	14,96	HIGH
Canal Construction using Precast Concrete	Precast Concrete	Precast Canal Installation	X.2.296	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Steel Sluice Gate Installation		Steel Sluice Gate Installation	X.2.355	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Trash Rack Installation		Trash Rack Installation	X.2.374	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Foundation		Pile Driving	X.2.404	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Culvert Construction	Precast Concrete	Culvert Installation	X.2.479	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Bridge Slab	Steel Plate Slab	Steel Plate Installation	X.2.672	Crane collapses due to poor ground-bearing capacity	14,96	HIGH
Cofferdam Demolition	Steel Sheet Pile	Steel Sheet Pile Removal	X.2.122	Workers below hit by steel sheet pile	14,72	HIGH
Soil Disposing to Disposal Area		Transporting Excavated Soil to Disposal Area	X.2.278	Heavy equipment vehicle brakes fail (hitting workers/people)	14,72	HIGH
Existing Utilities and Services Relocation Work		Telecommunications Utility Relocation	X.2.67	Worker electrocuted	14,72	HIGH
Utility Relocation Work		PLN Utility Relocation	X.2.700	Worker electrocuted	14,72	HIGH
Cofferdam Construction	Steel Sheet Pile	Steel Sheet Pile Driving	X.2.93	Workers below hit by steel sheet pile	14,72	HIGH
Cofferdam Construction	Steel Sheet Pile	Interlocking Connection	X.2.99	Workers below hit by steel materials	14,72	HIGH
Foundation	Pile	Pile Driving	X.2.407	Worker crushed by a pile	14,4	HIGH
Foundation	Pile	Pile Connection	X.2.412	Worker crushed by a pile	14,4	HIGH

Source: Processed by the author

The findings of 25 construction safety risks in the dominant irrigation network work, can be grouped into 3 groups based on the type of accident, namely heavy equipment accidents related to traffic accidents, heavy equipment accidents related to material lifting failures, and accidents due to electric shock.

The variables X.2.299, X.2.482, X.2.375, X.2.296, X.2.355, X.2.374, X.2.404, X.2.479, X.2.672, X.2.122, X.2.93, X.2.99, X.2.407, X.2.412 are the risk of heavy equipment accidents related to material lifting failures. This risk is the most dominant risk where 14 out of 25 of them are included in this risk group. As for lifting materials, in irrigation network work, Mobile Cranes are commonly used. This is due to the characteristics of irrigation network work that is spread over a large area, so lifting equipment that can move from one point to another is needed. However, material lifting activities using heavy equipment often cause the risk of being hit by falling objects and workers around them, as well as damage to transportation equipment due to this lifting failure. Construction materials that are not properly lifted can fall and fall on workers, causing injury or even death. This is in line with Kim and Kang (2022) who mentioned that until now major disasters caused by mobile cranes continue to occur all over the world, and because of their mobility, mobile cranes are more dangerous than other types of cranes, such as tower cranes, overhead cranes, and gantry cranes. Experts added that the use of mobile cranes on site is a tough challenge for contractors, where usually irrigation network work is very possible to be carried out in areas that have difficult access and with limited work areas. In addition, because it is commonly worked in areas near rice fields, mobile cranes often have difficulty in stabilizing their position so that they do not roll over and can safely carry heavy loads due to the poor soil bearing capacity to be used as a support. Therefore, lifting activities are one of the riskiest activities in this irrigation network work.

The variables X.2.277, X.2.4, X.2.271, and X.2.278 are the risk of heavy equipment accidents related to traffic accidents. The use of excavators, dump trucks, and cranes to carry out excavation work and transport materials can cause collisions or collisions with workers and the local communities, especially if the work zone is not properly regulated. This is in line with Tamara (2019) where in her research it is stated that heavy equipment contains a high risk of danger that can cause accidents if not handled properly and correctly. Experts added that the risk of heavy equipment accidents related to traffic accidents is very likely to occur in irrigation network projects because this irrigation network work has the characteristics of being carried out in difficult locations and it is not uncommon for access roads to reach work sites that are not in good condition. In addition, irrigation work is usually carried out in a wide area coverage and work zones that are not limited by fences, so in addition to workers, the surrounding community also has the potential to be affected. This characteristic makes heavy equipment accidents related to traffic have a fairly high probability of occurring and can have a significant impact not only on workers but also on the community around the work site.

The variables X.2.61, X.2.349, X.2.358, X.2.368, X.2.377, X.2.67, and X.2.700 are the risk of electric shock. This risk is quite common in irrigation network work due to the large use of pumps and welds in its activities. With the presence of electrical equipment in the work area exposed to water, the risk of electric shock increases. In addition, it is not uncommon for this risk to arise from utility relocation activities such as power cables and telecommunications. This is in line with Choi, Kim, and Jung (2024) who stated that in agricultural work environments, there are also risks related to exposure and safety hazards that are interrelated, similar to those found in industrial environments, and one of these potential risks is the risk of electric shock. This was added by Tamara (2019) who mentioned that electrical accidents such as being electrocuted or electrocuted can be caused by several things, namely planning, installation, and maintenance of electricity in the project environment does not refer to electricity standards and the provisions of laws and regulations. Experts added that outdoor work coupled with work locations that are relatively close to water can increase the chances of this risk of electric shock.

Impact of WBS-Based Construction Safety Risk Identification on Construction Safety Performance

This Irrigation Network Work Breakdown Structure (WBS) Standard has been developed at the level of work activities to improve construction safety performance. By identifying specific work activities in irrigation network projects, general construction safety risks can be recognized early in the project planning stage. Expert validation confirms that a clear structure facilitates the identification of construction safety risks at each stage of work, enabling the earlier implementation of preventive measures.

During the project planning process, the WBS can be utilized to detail safety measures more precisely. Each WBS element can be linked to relevant safety standards, enhancing the precision and comprehensiveness of the safety planning process. Consequently, the WBS Standard for Irrigation Network Projects includes a Construction Safety Management System work item, ensuring that this system receives adequate attention and resources throughout the project. The Construction Safety Management System is integral to project planning and preparation, ensuring that all occupational safety and health aspects are addressed before construction activities commence. This aligns with the proposals made by Veteto (1994), Mesaros, Spisakova, and Mackova (2019) , who argue that incorporating safety planning during the pre-construction phase can significantly enhance project safety performance and improve the effectiveness of safety management. Schoonwinkel, Fourie, and Conradie (2016) also noted that changes made during the construction phase have a more significant cost impact than modifications made during the initial project phase.

CONCLUSION

This study resulted in a WBS Standard Construction Safety Risk Level for the Irrigation Network Project, which a panel of experts validated. The WBS structure includes 1 Project Name, 8 Work Clusters, 26 Work Types, 67 Work Packages, and 177 Activities. All experts agree that breaking down work items to the level of work activities (WBS Level 5) can enhance construction safety performance in irrigation network projects. This is achieved through a more structured division of tasks and more detailed safety planning and implementation. By effectively detailing project deliverables at the work activity level, each activity within the irrigation network can be more accurately identified.

In this study, 708 risk factor variables that affect construction safety performance in irrigation network work were also validated, of which 25 were the dominant risk factors in irrigation network work. The risk of heavy equipment accidents related to material lifting failure is the most dominant risk where 14 out of 25 of them are included in this risk group. This is because usually irrigation network work is very possible to carry out in areas that have difficult access and with limited work areas

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