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Page. 47 - 62

Cost Analysis of the Construction Safety Management System (SMKK) Based on Work Breakdown Structure (WBS) in an Irrigation Project

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ABSTRACT
Infrastructure development, particularly water infrastructure such as irrigation channels, plays a crucial role in regional development. In its implementation, construction safety becomes a critical aspect. The Construction Safety Management System (SMKK), as regulated in the Indonesian Ministry of Public Works and Housing Regulation No. 10 of 2021, serves as a guideline for ensuring safety in construction projects. One of the key components of SMKK is the accurate cost planning based on risk control programs for each activity, analyzed through a Work Breakdown Structure (WBS) approach. This research aims to develop a cost estimation of the SMKK using a Work Breakdown Structure (WBS)-based approach tailored to irrigation construction projects.The research includes identifying detailed work packages and activities, analyzing potential hazards and risks, formulating occupational health and safety (OHS) objectives and programs, and estimating SMKK costs in a case study of the DI. Saddang Irrigation Rehabilitation Project. The results provide a structured WBS framework, a comprehensive risk profile, and an estimated SMKK cost distribution, in which the largest portion is allocated to safety personnel, followed by training, personal protective equipment, and insurance.
KEYWORDS Work Breakdown Structure, Construction Safety Management System (*Sistem Manajemen Keselamatan Konstruksi*), Safety Cost

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1. INTRODUCTION

Water infrastructure development, particularly irrigation systems, plays a strategic role in supporting food security and regional development. However, its implementation presents considerable occupational health and safety challenges. According to data from the Indonesian Workers Social Security Agency (BPJS Ketenagakerjaan), the construction sector continues to report a high number of work-related accidents. To address this issue, the Ministry of Public Works and Housing (PUPR) issued Regulation No. 10 of 2021, establishing the Construction Safety Management System (SMKK) as a national guideline. This regulation emphasizes the importance of risk control programs and the appropriate, proportional cost planning in construction safety management.

The SMKK framework begins with structured and detailed cost planning. As outlined in the PUPR Regulation, nine mandatory cost components must be included in the safety planning documents by construction service providers. Accurate estimation of these cost components is expected to improve safety performance and reduce accident rates in construction projects.

In practice, however, several challenges are encountered. One of the major issues is the lack of standardized, detailed methodologies for estimating SMKK costs. In many cases, SMKK budget allocations are based on lump-sum values or percentages of the total project cost, rather than on a structured analysis of work activities and associated risks. From the contractor's perspective, cost items such as personal protective equipment (PPE), HSE training, and safety signage are often included in the Bill of Quantity (BQ) as generalized, non-itemized entries, lack of standardization of a systematic framework for cost breakdown. This lack of standardization limits the accuracy and relevance of SMKK cost planning to actual field requirements.

To address this gap, this study aims to develop an SMKK cost estimation model based on a detailed Work Breakdown Structure (WBS) for irrigation construction projects. The research takes the Rehabilitation and Modernization Project of the D.I. Saddang Irrigation System in South Sulawesi Province as a case study. Specifically, this study seeks to:

1. Identify detailed work packages and activities in the irrigation project;
2. Identify hazards, risks, and safety control plans in irrigation construction;
3. Identify occupational health and safety (OHS) objectives and programs, as well as SMKK cost components based on the WBS approach in irrigation construction;
4. Estimate SMKK (Construction Safety Management System) costs in a case study irrigation project based on the identified OHS programs and components.

2. LITERATURE REVIEW

2.1 Case Study Project: Rehabilitation and Modernization of D.I. Saddang Project

The Langnga Irrigation Sub-Area is a part of the Langnga Irrigation Area (D.I. Langnga) located in Pinrang Regency, South Sulawesi. It is approximately 185 km from Makassar City, with a travel time of around 3.5 hours by car. The total irrigated area covered by the D.I. Saddang Sub Unit Langnga is 6,160 hectares (SNVT PJPA BBWS Pompengan Jeneberang, 2022). The Rehabilitation and Modernization Works of D.I. Saddang Sub Unit Langnga focus on improving irrigation infrastructure facilities and utilities to enhance their function and ensure optimal service.

Table 1. General Project Information

Project Name	:	Rehabilitation and Modernization of D.I. Saddang Sub Unit Langnga
Location	:	Pinrang Regency, South Sulawesi
Client/Owner	:	SNVT for Water Resource Utilization Network Implementation, BBWS Pompengan Jeneberang, South Sulawesi Province
Design Consultant	:	Oriental Consultants Global Co. Ltd.
Supervision Consultant	:	Korea Rural Community Corporation in Joint Venture with PT. Indra Karya (Persero), PT. Multimera Harapan, and PT. Hilmy Anugerah
Main Contractor	:	PT. XYZ
Contract Date	:	May 9, 2022
Construction Duration	:	600 Calendar Days
Maintenance Period	:	360 Calendar Days
Contract Value	:	Rp 95,616,237,000 (Excl. VAT) – Addendum III: Rp 105,177,860,000 (Excl. VAT) Addendum III menjadi Rp. 105.177.860.000 (Exc. PPN)
Finding Source	:	*Strategic Irrigation Modernization and Urgent Rehabilitation Project* (SIMURP), IBRD Loan No. 8891-ID and AIIB Loan No. L0060A

Source: PT. XYZ (2022), processed by Author

The project includes rehabilitation, and modernization works for 10 irrigation canals, covering both secondary and tertiary channels. The scope includes major construction activities such as earthworks (excavation, embankment, compaction), canal structure improvements (lining, division structures, gates, concrete works), inspection roads (for maintenance and operational access), and water control infrastructure to ensure efficient and effective irrigation water distribution tailored to agricultural needs.

2.2 Construction Safety Management System (SMKK)

The Construction Safety Management System (SMKK) is a mandatory system implemented in all construction projects as stipulated in the Regulation of the Minister of Public Works and Public Housing (PUPR) No. 10 of 2021. SMKK aims to ensure construction safety, which includes engineering safety, occupational health and safety (OHS), public safety, and environmental protection at the project site. SMKK is embedded in the construction management system, making safety a fundamental part of the project culture—not just a legal requirement but also a fundamental part of the work culture. SMKK implementation covers three main stages: selection of service providers, execution of works, and handover of the completed work. At each stage, SMKK is documented in Construction Safety Plans (RKK), Quality Plans (RMPK), and Traffic Management Plans (RMLLP). SMKK implementation costs must be explicitly specified explicitly stated in procurement and execution documents, including the Owner's Cost Estimate (HPS) and the contractor's Budget Plan (RAB).

The cost components of SMKK as outlined in PUPR Regulation No. 10 of 2021 and SE Dirjen Bina Konstruksi No. 68/2024 include:

1. SMKK documentation,
2. Safety awareness campaigns, training, and promotion,
3. Personal protective equipment (PPE),
4. Workers' insurance,
5. Safety personnel,
6. Health facilities and infrastructure,
7. Traffic signs and equipment,

8. Safety expert consultations, and
9. Other risk control-related activities and equipment.

2.3 Irrigation Works and Irrigation Construction Methods

An irrigation network consists of several physical components, ranging from the main canal, tertiary canals, buffer zones, to drainage canals. Each component serves a specific function to ensure the efficient distribution and disposal of water to support agricultural irrigation. According to Kementerian Pekerjaan Umum (2013), the components are:

1. Main Irrigation Canal: Delivers water from the weir to secondary canals and tertiary blocks. The boundary of the main canal usually ends at the final division structure.
2. Tertiary Irrigation Canal: Carries water from the tertiary intake structures in the main network into tertiary blocks and onward to quaternary canals, which supply water directly to fields.
3. Canal Buffer Zone: Established to protect irrigation channels and structures, its width is determined by regulations.
4. Tertiary Drainage Canal: Located within tertiary blocks, this canal collects water directly from fields and discharges it into the tertiary drainage network.
5. Main Drainage Canal: Collects water from the tertiary drainage network and flows into the primary drainage system or natural water bodies such as rivers or the sea.

Based on Pasaribu (2018), irrigation construction consists of several major components:

1. Mobilization: Transporting equipment, materials, personnel, and support facilities (offices, labs, warehouses, etc.)
2. Demobilization: Returning those assets after project completion
3. Earthworks: Includes surface clearing, excavation (soil, rock, soft soil), disposal, and backfill/borrow embankments
4. Structural Works: Depends on project conditions and budget; may involve precast elements, in-situ concrete, stone masonry, or gabion works
5. Inspection Road Construction: May include sub-base layer compaction, crushed stone (macadam), or concrete pavement
6. Water Control: Involves the supply and installation of water gates and their accessories
7. Miscellaneous Works: Includes signage, information boards, utility relocation, and MEP/SCADA works

2.4 Work Breakdown Structure (WBS)

According to the (Project Management Institute, 2017), a Work Breakdown Structure (WBS) is a hierarchical decomposition of the project's deliverables-oriented tasks to be carried out by the project team. It is the first step after defining the project scope and requirements. WBS development also supports scheduling, configuration management, budgeting, and performance measurement. As identified by Pasaribu (2018), a standard WBS structure for irrigation construction consists of:

1. WBS Level 1: Project Name
2. WBS Level 2: Work Cluster
3. WBS Level 3: Work Type
4. WBS Level 4: Work Package
5. WBS Level 5: Activity
6. WBS Level 6: Resource

2.5 Conceptual Framework

In this study, Variable X represents the planning and calculation of SMKK costs in irrigation construction projects, based on the Work Breakdown Structure (WBS). This includes nine main components, namely:

- X.9.1 – SMKK documentation,
- X.9.2 – socialization, promotion, and training,
- X.9.3 – provision of protective equipment (PPE),
- X.9.4 – insurance and work permits,
- X.9.5 – safety personnel,
- X.9.6 – health facilities and infrastructure,
- X.9.7 – traffic signs and safety equipment,
- X.9.8 – consultation with safety experts,
- X.9.9 – other risk control-related activities.

These components are structured based on the WBS of irrigation construction works and are used as the foundation for estimating SMKK costs.

3. METHODOLOGY

The research strategy employed in this study includes document analysis, risk analysis, expert validation, and expert interviews. The research was carried out in five main stages. The first stage begins with a preliminary study through literature review and policy analysis related to the Construction Safety Management System (SMKK), particularly within the context of irrigation projects. Initial activities include problem identification, formulation of research questions, and the selection of appropriate research methods.

Next, research variables and indicators are identified, followed by document and data analysis to answer Research Question 1 (RQ1) concerning work packages and irrigation activities. The output from this stage is a validated Work Breakdown Structure (WBS), achieved through expert validation.

The second stage involves the development and validation of questionnaires for RQ2 and RQ3. This process is followed by descriptive and qualitative risk analysis to identify potential hazards, risk levels, and control objectives and programs based on the WBS.

In the third stage, a questionnaire for RQ4 is prepared and validated, focusing on the identification of SMKK cost components. A descriptive analysis is then conducted to produce a validated list of SMKK cost components related to risk control measures.

The final stage in this study involves the preparation and validation of a questionnaire for RQ5, which aims to compare the planned and actual SMKK costs in the case study project. This analysis provides insights into the ideal SMKK cost based on WBS and identify the gap between estimated and actual costs in the field.

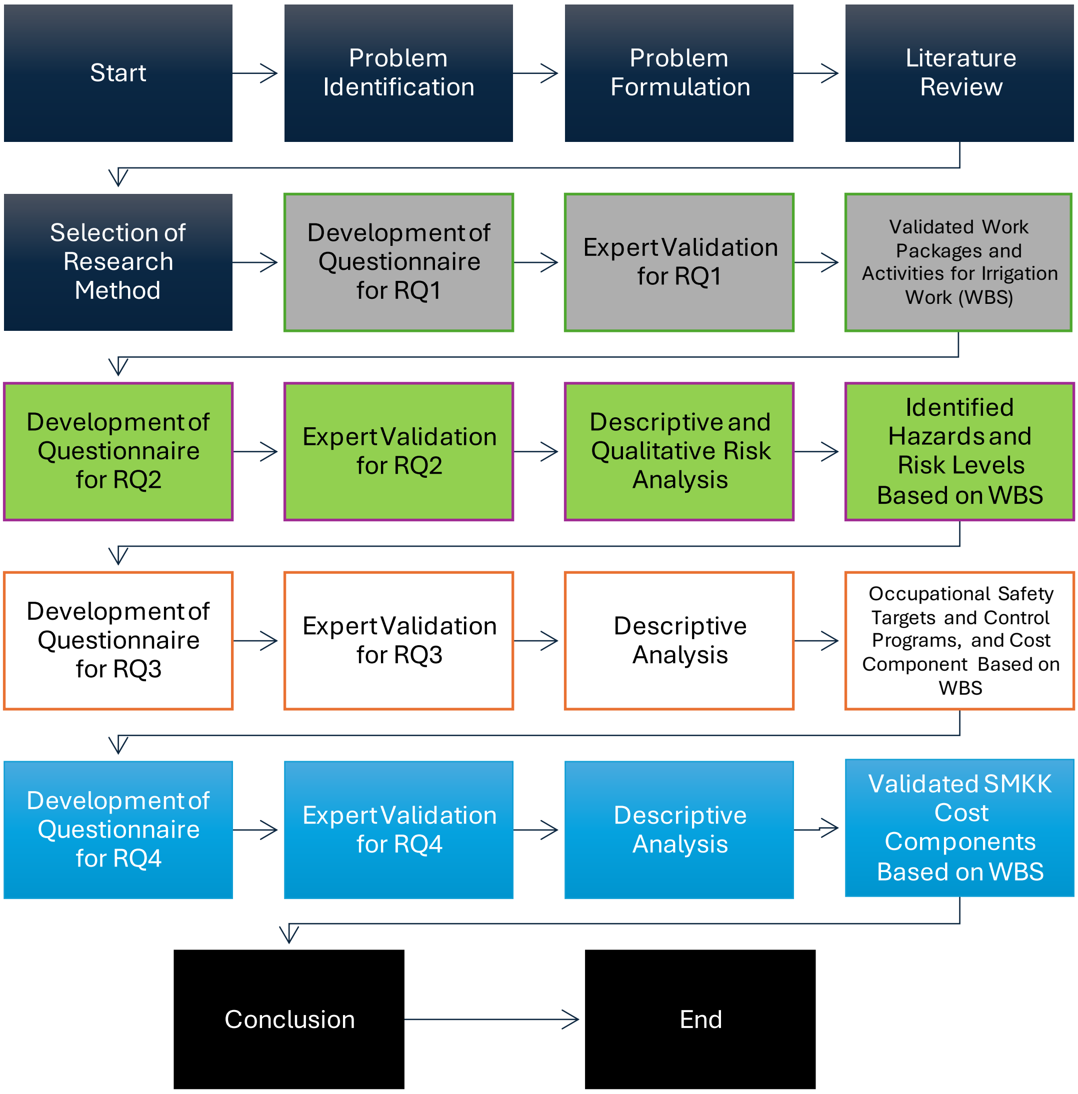

Figure 1. Research Methodology Flow
Source: Author's Analysis (2025)

4. RESULTS & DISCUSSION

4.1 Research and Discussion for RQ 1

Based on the data collection results to answer RQ 1, a validation process was carried out regarding the variables of work packages (X.1) and activities (X.2) that had been compiled for irrigation channel work. The final output of this stage is a set of validated main work packages and technical activities that are systematically structured in the form of an irrigation Work Breakdown Structure (WBS), which serves as the foundation for risk identification and safety control in the subsequent stages of this study.

The results of the standard WBS for irrigation/channel projects are as follows:

1. WBS Level 1: Project Name
2. WBS Level 2: Work Classification (13 classifications)
3. WBS Level 3: Work Type (26 work types)
4. WBS Level 4: Work Package (89 work packages)
5. WBS Level 5: Activities (160 activities)

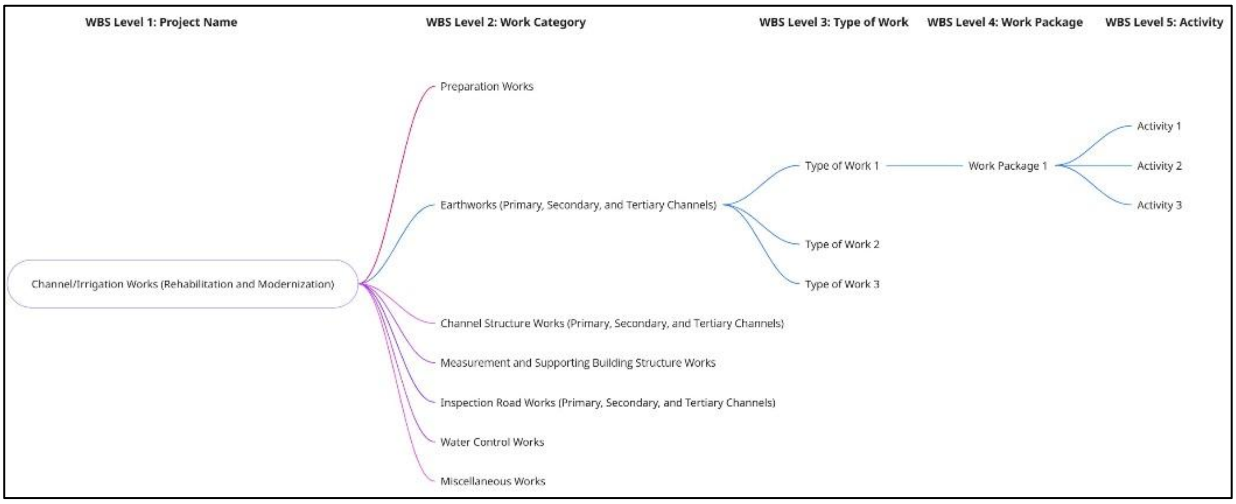

Figure 2. Development of WBS for Channel/Irrigation Work
Source: Author's Analysis (2025)

4.2 Research and Discussion for RQ 2

To answer RQ 2, a series of analyses were conducted on the expert validation results regarding the identification of hazards and risks in irrigation channel construction work. First, the variables of hazard and risk identification (X.3) were analyzed using the mode value approach to determine dominant hazard potentials based on expert perception. Then, a qualitative risk analysis was conducted to determine the frequency and impact of each identified hazard. These values were then used to calculate the risk level (X.4).

Based on the results, risk control (X.5) was focused on activities with medium and high-risk levels to ensure that mitigation strategies are effectively directed at the most significant risk sources. The findings of this process yielded the following:

1. A total of 852 hazards and risks were validated and deemed to require further control out of 867 identified items.
2. For the work type "SMKK Implementation" (WBS Level 3), no hazards or risks were identified, as this work type is classified as a control program intended to mitigate hazards and does not directly pose safety threats.

From the 852 validated hazards and risks, 380 were categorized as low risk and 472 as medium risk. No high-risk hazards were identified by the majority of experts. This is attributed to the relatively lower complexity of hazards and risks in irrigation work compared to other infrastructure types such as dams, bridges, or ports. These findings align with previous studies by Utama (2020), which also reported no major risks in irrigation construction projects. Although irrigation projects cover wider areas, the scope of work tends to be more typical and less complex than other infrastructure.

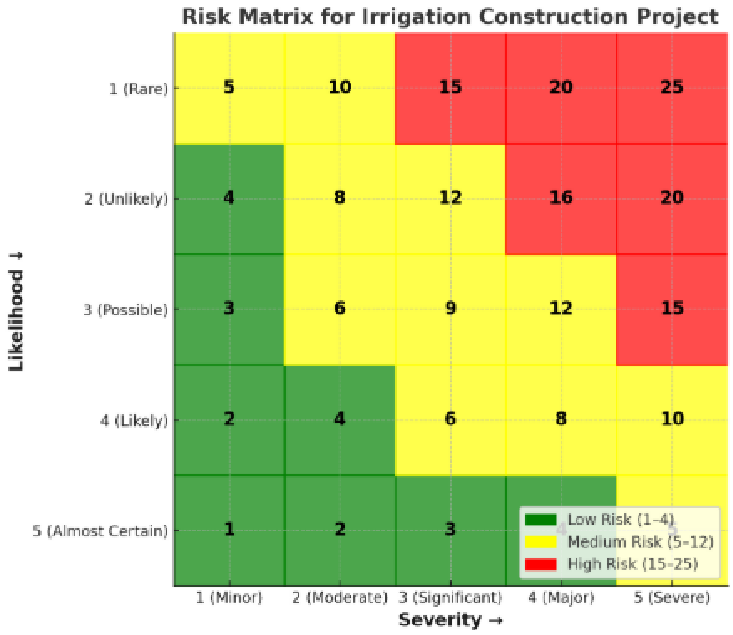

Figure 3. Risk Matrix for Irrigation Construction Project

Table 2. Types of Hazards and Risks

No.	Hazard Type (Simplified)	Risk Description (Simplified)	Risk Value (F × D)	Risk Level	Risk Rank
1	Oil/fuel spill from equipment/vehicles	Soil and water pollution affecting health/environment	12	Medium	1
2	Fall from height	Injury, bone fracture, fatality	12	Medium	1
3	Slip during formwork installation at height	Injury, fracture	12	Medium	1
4	Excavated/fill materials dirtying access roads	Traffic accidents	12	Medium	1
5	Dust pollution from mixing	Respiratory issues (e.g., infection)	12	Medium	1
6	Concrete spill on roads	Slippery roads, traffic accidents	12	Medium	1
7	Bar cutter injury	Serious hand/finger injury	12	Medium	1
8	Lightning strike	Burn injury, fatality	12	Medium	1
9	Falling zinc material stepped on by workers	Minor injury, property damage	9	Medium	2
10	Fall from canal edge	Injury due to slipping	9	Medium	2
11	Washed away by water current	Injury, bone fracture, fatality	9	Medium	2
12	Equipment slipping into canal	Equipment damage due to unstable ground	9	Medium	2
13	Traffic accident during transport	Equipment damage, delays, repair costs	9	Medium	2
14	Noise at project site	Hearing issues for workers	9	Medium	2
15	Increased sedimentation	Decreased water quality	9	Medium	2
16	Sharp tool cuts (e.g., sickles, saws)	Injury, bone fracture	6	Medium	4
17	Cement splatter during casting	Eye irritation	6	Medium	4

No.	Hazard Type (Simplified)	Risk Description (Simplified)	Risk Value (F × D)	Risk Level	Risk Rank
18	Improper material stacking	Material loss, financial loss	6	Medium	4
19	Workers cut by zinc fence	Minor cuts, muscle strain	6	Medium	4
20	Workers hit by overturned heavy equipment	Fatal injuries (fracture, death)	6	Medium	4
21	Workers hit by equipment movement	Serious injuries from collisions	6	Medium	4
22	Vehicle tip-over or slip	Equipment damage, traffic congestion	4	Low	5
23	Exploding vehicle tire	Potential traffic incident	4	Low	5
24	Workers injured by hand tools	Minor to moderate injuries	4	Low	5
25	Worker fatigue	Poor construction quality	4	Low	5
26	Wood dust or ash exposure	Eye irritation	4	Low	5
27	Workers buried by excavation materials	Minor to serious injuries	4	Low	5
28	Wet/slippery surface slip	Injury, fracture	3	Low	6
29	Untrained equipment operators	Severe injury from equipment accident	3	Low	6
30	Workers electrocuted (wet environment)	Electric shock, burn	3	Low	6
31	Falling roof frame/materials	Injuries or fractures	3	Low	6
32	Workers pierced by rebar or wire	Minor to moderate injuries	3	Low	6
33	Falling rocks or tools	Head/hand injury	3	Low	6
34	Workers injured by water well drill	Muscle/bone injury, fatality	2	Low	7
35	Cable short circuit/fire	Property damage, asset loss	2	Low	7
36	Heat stress	Dehydration, occupational illness	2	Low	7
37	Uneven ground slips	Injury or fracture	2	Low	7
38	Soft soil damages vehicle tracks	Vehicle stuck, recovery required	2	Low	7
39	Hit by material while loading/unloading	Minor to moderate injuries	2	Low	7
40	Concrete mixer accidents	Mild to severe injury	2	Low	7
41	Landslide in canal wall	Minor to moderate injury	2	Low	7
42	Injury from lifting heavy loads (manual transport)	Muscle/bone strain	2	Low	7
43	Injury from plastering tools	Cuts or bruises from sharp edges	2	Low	7
44	Environmental pollution from domestic solid waste	Environmental impact	2	Low	7
45	Hazardous mixer movement	Risk of collision or entrapment	2	Low	7
46	Prolonged computer exposure	Long-term vision issues	2	Low	7
47	Poor ergonomics at workstation	Muscle injury from poor posture	2	Low	7
48	Uncalibrated test equipment	Inaccurate testing results	1	Low	8
49	Poor concrete quality	Substandard concrete strength	1	Low	8
50	Poor reinforcement of steel quality	Structural failure risk	1	Low	8
51	Non-spec aggregate/soil	Structural failure risk	1	Low	8

Source: Author’s Analysis (2025)

Risk control strategies were formulated based on activities categorized with medium to high risk levels, referring to the Ministry of Public Works and Housing Regulation No. 10 of 2021 and Circular No. 68/2024. The identification of control measures was arranged according to the hierarchy of controls, ordered from the most to least effective.

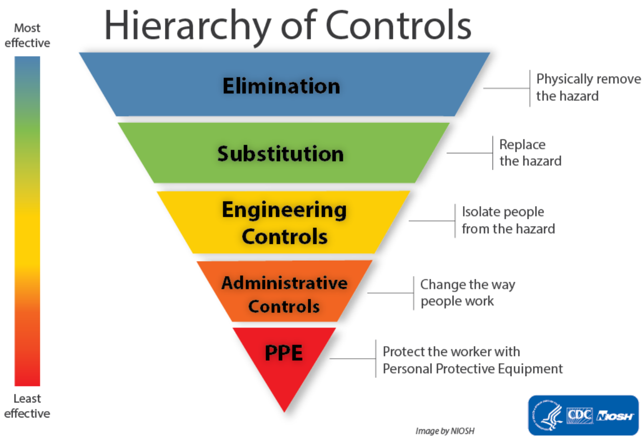

Figure 4. Hierarchy of Risk Control
Source: (National Institute for Occupational Safety and Health (NIOSH), 2024)

Summary of key findings from the hazard and risk control program in irrigation projects based on the hierarchy of controls:

1. Elimination: Not implemented as irrigation work is physical and heavy equipment usage cannot be fully eliminated.
2. Substitution: Includes material/method changes, such as using scaffolding instead of wood frames, safer fencing materials (PVC/non-reflective), drone usage for measurements, and relocating batching plants away from residential areas.
3. Engineering Controls: Environmental modifications such as installing signage, fall protection platforms, washing bays, special fabrication zones, and safety fencing.
4. Administrative Controls: Includes JSA evaluations, validation of equipment/operators, emergency training, safety briefings, flagmen assignments, and procedural inspections.
5. PPE (Personal Protective Equipment) Controls: Used as the last line of defense, including mandatory PPE (helmets, vests, safety shoes) and additional equipment based on hazards (masks, full body harnesses, earplugs, gloves, etc.).

4.3 Research and Discussion for RQ 3

At this stage, the objectives, programs, and SMKK cost components for irrigation projects were established, based on the results of previous risk identification and control analysis. Control objectives and programs were defined using the risk level classification (medium and high) derived from RQ 2, and by referring to the structure outlined in the Ministry Regulation No. 10/2021. The determination of SMKK cost components was based on the resources outlined in each control program, which correspond to the nine components of SMKK.

All phases, formats, and provisions for setting objectives, programs, and SMKK cost components referred to the Construction Safety Plan (RKK) structure as regulated in the same Ministry Regulation. This stage focuses on the Special Program Resource Components, which are the basis for estimating the cost requirements of each risk control effort.

Key findings in determining SMKK Cost Components include: training and promotion needs for high-risk workers, proportionate allocation of field safety personnel due to the dispersed nature of irrigation work locations, and specific PPE needs based on hazard types. Additional requirements were also identified, such as health facilities, work signage, and administrative support like safety audits and document preparation. These needs are converted into cost units based on activity type, frequency, and quantity estimates suited to the context of the irrigation project, which will be elaborated in the following section.

4.4 Research and Discussion for RQ 4

This stage involves determining the total SMKK costs for the case study project: Rehabilitation of D.I. Saddang. The cost estimation is based on the required resources from the control objectives and programs aligned with their respective components. The SMKK cost breakdown follows Regulation No. 10/2021, Circular No. 68/2024, and Alya Bonitha et al. (2024), validated by five experts. The result is a cost summary of SMKK calculations for the irrigation project as shown below:

Table 3. Recapitulation of SMKK Costs for the Irrigation Project (D.I. Saddang)

No	Work Description	Total Cost (IDR)	Percentage (%)
1	Preparation of SMKK Documents	Rp. 20,840,000.00	1.19%
2	Socialization, Promotion, and Training	Rp. 308,032,800.00	17.57%
3	Work Protection Equipment and PPE	Rp. 240,944,573.00	13.74%
4	Insurance (CAR)	Rp. 382,464,948.00	21.81%
5	Construction Safety Personnel	Rp. 660,000,000.00	37.64%
6	Health Facilities, Infrastructure, and Equipment	Rp. 17,770,400.00	1.01%
7	Signage and Traffic Equipment	Rp. 69,232,312.00	3.95%
8	Expert Consultation on Construction Safety	Rp. -	0.00%
9	Other Risk Control Activities and Equipment	Rp. 69,111,089.00	3.91%
	Total SMKK Cost	**Rp. 1,768,396,122.00**	
	Total Contract Value	**Rp. 95,616,237,000.00**	
	SMKK Cost Percentage to Contract Value	**1.85%**	

Source: Author's Analysis (2025)

From these findings, the SMKK cost plan based on the nine safety components as per Ministerial Regulation No. 10/2021 amounts to 1.85% or Rp. 1,768,396,122 of the total project value of Rp. 95,616,237,000.

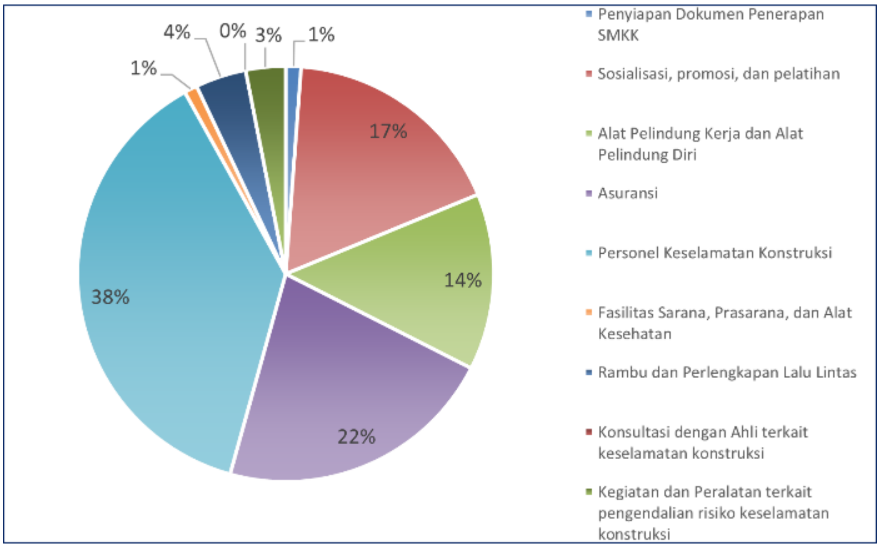

Figure 5. Cost Percentage Diagram of SMKK Components for D.I. Saddang Rehabilitation Project
Source: Author's Analysis (2025)

Based on the pie chart illustrating the proportional distribution of SMKK cost components in the irrigation project, it is evident that the largest portion of the budget is allocated to Construction Safety Personnel, followed by Construction All Risk (CAR) Insurance, and Socialization, Promotion, and Training Programs. These three components dominate the total SMKK expenditure, indicating that human resource readiness, financial risk protection, and safety culture development are core priorities in the safety management strategy. The remaining components—including Personal Protective Equipment (PPE), health facilities, expert consultations, traffic signs, and risk control equipment—though contributing smaller individual shares, collectively form the necessary support framework for comprehensive construction safety implementation.

In detail, Construction Safety Personnel emerged as the most dominant cost component, accounting for 37.64% of the total estimated SMKK cost, equivalent to Rp. 660,000,000.00. This significant portion is attributed to the long project duration (20 months) and the proportional quantity of safety personnel required, such as construction safety experts and officers, aligned with the project's high-risk classification (large-scale). In addition, the presence of flagmen and paramedics was adjusted to meet the site-specific needs of the project. Several experts (Expert 2 and Expert 4) opined that the cost of construction safety personnel should be included in general project expenses, as it relates to personnel and human resources management. However, based on the consensus of the majority of consulted experts, this study retains the inclusion of such costs within the SMKK framework. The estimation was made using a unit price approach based on empirical analysis of project documentation and the local minimum wage (UMP) rates.

Construction All Risk (CAR) Insurance represents a significant portion of the SMKK cost, amounting to 21.81% or Rp. 382,464,984.00. This allocation reflects the importance of financial protection against accidents and potential damage during construction activities. The 0.4% value of the total contract was derived from a third-party assessment, considering various factors such as deductible value, potential project risks, and the required coverage scope. Each project may yield different coefficient values based on its unique risk profile and characteristics, emphasizing the need for customized insurance planning.

Socialization, Promotion, and Training Programs constitute a critical element in the success of SMKK implementation, contributing 17.57% or Rp. 308,032,800.00 of the total cost. These programs focus on safety induction for staff and visitors, regular safety briefings, safety meetings, and specific training sessions addressing high-risk activities—designed according to assumed worker turnover schedules.

These activities are conducted routinely and systematically, with frequency adjusted to the project's risk level and duration. The programs also include emergency response simulations and health awareness campaigns for infectious disease prevention. Complementary media, such as banners, posters, and safety boards, are integral components to strengthen safety culture at the construction site.

Work Protection Equipment (APK) and Personal Protective Equipment (PPE) are crucial in safeguarding construction workers on irrigation projects. These components accounted for 13.74% of the estimated SMKK cost, or Rp. 240,944,573.00.

The cost was based on various types of PPE and APK tailored to the risk characteristics of the field activities, including basic equipment (e.g., safety helmets, gloves, safety shoes) and specialized gear (e.g., full-body harnesses, life vests, respiratory protection). The quantity estimation considered the number of workers, worker turnover risk (using a loss factor coefficient as per Alya Bonitha et al., 2024), work duration, and risk-adjusted usage cycles. This approach ensures that the provided protective equipment meets the actual safety demands of the fieldwork.

5. CONCLUSION

1. RQ 1 produced a validated irrigation construction work structure consisting of 13 work groups, 26 work types, 89 work packages, and 160 detailed activities. This structure served as the foundation for developing the Work Breakdown Structure (WBS) for further safety planning and cost estimation.
2. RQ 2 identified 852 types of hazards and risks, including 380 categorized as low risk and 472 as moderate risk. Control programs were proposed particularly for low-risk hazards using the hierarchy of control approach to ensure effective mitigation.
3. RQ 3 formulated the objectives and risk control programs aligned with the identified hazards, resulting in a comprehensive list of programs accompanied by their implementation timeline, performance indicators, required resources, and responsible personnel. This information was then utilized to define the cost components of the Construction Safety Management System (SMKK) in compliance with PUPR Regulation No. 10 of 2021.
4. RQ 4 estimated the SMKK cost based on actual needs for each control program. The total cost amounted to Rp. 1,768,396,122, equivalent to approximately 1.85% of the total project value. The analysis showed that the Construction Safety Personnel component accounted for the largest portion of the cost (37.64%), followed by Construction All Risk (CAR) Insurance (21.81%), Safety Training and Promotion (17.57%), and Work and Personal Protective Equipment (13.74%).

5.1 Practical Implication

This research provides a structured methodology for estimating SMKK (Construction Safety Management System) costs in irrigation projects using a risk-based and Work Breakdown Structure (WBS) approach. The findings contribute to more accurate and accountable budgeting practices by aligning cost planning with actual project risks and control needs. Practitioners—particularly safety planners and contractors in the water infrastructure sector—can adopt the SMKK cost components and estimation methods from this study to improve the quality and effectiveness of construction safety implementation. Furthermore, the developed framework supports compliance with PUPR Regulation No. 10 of 2021 by translating its principles into quantifiable and actionable cost components. This approach bridges the gap between regulatory requirements and on-site safety needs, promoting a more proactive and context-driven safety culture.

5.2 Limitation and Future Research

This study is limited to a single case study of an irrigation project in South Sulawesi Province, which may affect the generalizability of the findings to other types of infrastructure or regional contexts. The SMKK cost estimation relies on assumed worker turnover rates, local minimum wage data, and expert input, which may vary in other projects. Furthermore, the scope of this research does not include a comparative analysis of cost realization data or the direct impact of SMKK implementation on lagging safety indicators.

Future research is recommended to:

1. Apply this framework to various types of construction projects (e.g., roads, bridges, housing) to validate its adaptability;
2. Develop a standardized unit cost database for each SMKK component;
3. Integrate digital tools for real-time SMKK cost tracking and reporting;
4. Explore the relationship between SMKK investment and improvements in safety performance metrics over time.

6. ACKNOWLEDGEMENT

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