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Identification of critical activities and associated risks in microtunnelling construction projects

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ABSTRACT

Project X is forecasted to experience delays primarily due to discrepancies between tender assumptions and actual site conditions. This study aims to identify critical activities in microtunnelling construction projects and their associated risk factors. The findings are expected to provide a reference framework for effective monitoring and evaluation of schedules in microtunnelling projects in Indonesia. Archival and historical data, including construction schedules and Work Breakdown Structure (WBS) documents of method statements, were collected to identify critical activities. Questionnaires and interviews were conducted with at least three experts to determine the risk factors contributing to the criticality of these activities. The results indicate that critical activities in microtunnelling projects can be categorised by work type, including permitting, preparation, shaft, pipe jacking, manhole, diversion chamber, reinstatement, administrative, and testing and commissioning works. Furthermore, various risk factors were identified across these activities, including administrative, external conditions, geological, technical, and country-related risks at the construction location, as well as safety risks related to human factors.

KEYWORDS

Work Breakdown Structure, Critical Activity, Microtunneling Construction, Delay Risk

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1. INTRODUCTION

The City of Jakarta requires the development of a Sewerage System (wastewater pipeline system), driven by the following factors (Dokumentasi Proyek JSDP Paket 3, 2023):

1. Without improvements to the domestic sewerage management system, the Jakarta Special Capital Region (DKI Jakarta), in the context of both population and economic growth, will experience a decline in water quality.
2. The coverage of wastewater treatment services in Jakarta currently ranges from only 6% to 10%,
3. A centralised sewerage management system can significantly improve public health and environmental quality when properly developed and enhanced.
4. The development of such systems constitutes a critical measure to reduce contamination by Escherichia coli (E. coli), which is associated with diarrhea and other potentially fatal gastrointestinal diseases.

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Based on the Risk Breakdown Structure (RBS) derived from a pilot survey (preliminary questionnaire) administered to experts deemed to have significant involvement in the project, the identified risks were classified as high and medium-high level within the categories of stakeholder-related risks, subcontractor performance risks, subcontractor financial capability risks, technical site condition risks, and client professionalism risks. Previous studies indicate that pipe jacking involves complex risks, including geological conditions, site conditions, groundwater, construction execution, administrative aspects, design, management, contractual errors, and resource monitoring (Shelake et al., 2022). The risks that occurred during the course of the project were documented and compiled, including a summary of their time impacts on delayed activities resulting from the actual risks encountered.

Table 1. Summary of Project X Delay Activities

No.	Location	Delayed Activity	Start Delay Duration (Days)	Total Project Delay Duration (Days)
1	C-24.0 Open Caisson	Temporary works were delayed due to a lack of approval from the Transportation Agency (Dishub), resulting in cascading delays in subsequent activities and affecting the overall project completion date.	130	79
2	C-24.1 Open Caisson	Temporary traffic management activities could not be executed as scheduled due to the Transportation Agency's decision to issue the press release only after the completion of locations C-24.2 and C-24.0.	272	79
3	C-24/2.1 Steel Sheet Pile Shaft	Preparatory work for fence installation was halted by PT Pembangunan Jaya Ancol's security personnel despite approvals from the Highways Agency (DBM) and the Transportation Agency, due to additional insurance requirements that fall outside the contract scope.	136	67
4	C-18.1 & C-18.2 Steel Sheet Pile Shaft	Sheet pile driving activities were delayed due to obstacles in relocating PDAM transmission pipelines, resulting in cascading delays for subsequent activities and affecting the overall project completion date.	172	149
5	C-18.3, C-19.0 & C-20.0 Steel Sheet Pile Shaft	SSP driving activities could not commence until the relocation of PDAM pipelines (500 mm and 600 mm diameters) was completed.	310	149
6	C-24.1 Open Caisson	Soil improvement works could not commence until the relocation of the 600 mm PDAM pipeline was completed	382	138
7	C-18.0 Steel Sheet Pile Shaft	Sheet pile driving could not commence until the consultant completed the design due to MRT interface constraints	148	109
8	C-24.2 Open Caisson	Structural works for Segment 1 experienced delays and could not be completed in accordance with the baseline program	39	88

Sources: (Dokumentasi Proyek JSDP Paket 3, 2024)

Project X is forecast to experience a 149-day delay, primarily due to discrepancies between tender assumptions and actual site conditions. Permit acquisition took longer than planned; some work areas were located on private land, requiring additional coordination; and limited information on utility clashes led to an underestimation of test-pit activities. In addition, reduced subcontractor productivity and unforeseen geological conditions further contributed to the delay. These delays may also lead to contractual disputes and reduced project quality due to time pressure and reliance on alternative materials.

If not properly managed, such delays may lead to time overruns, increased overhead costs, contractual disputes, and reduced project quality due to time pressure and reliance on alternative materials. From a corporate perspective, delays may also reduce revenue and negatively impact the company's reputation (Dokumentasi Proyek JSDP Paket 3, 2025). This study aims to identify critical activities in microtunnelling construction and the associated risk factors for each. The findings are expected to contribute to the development of time and risk management strategies for similar microtunnelling construction projects in Indonesia.

2. LITERATURE REVIEW

2.1. Microtunneling Project

Pipe jacking is a trenchless construction method widely used to install and maintain underground pipeline networks in urban areas. As an environmentally friendly construction technique, it can install pipes ranging from 100 mm (4 inches) to 5,000 mm (200 inches), accommodating most urban pipeline infrastructure requirements. Furthermore, this method is regarded as the most widely utilised trenchless technique in Japan (Ma et al., 2023).

The pipe jacking method (see illustration in Figure 1) is a trenchless technology that enables engineers to construct specialised pipeline systems, even over long distances and along curved alignments such as S-shaped configurations, within densely populated urban underground environments without disrupting normal city activities (Thomson, 2013; Zhang et al., 2018). A key characteristic that distinguishes this method from other trenchless techniques is that precast pipes are jacked along a predetermined alignment from the launching shaft to the receiving shaft, rather than being constructed progressively in situ with segmental lining installed behind the excavation face or within the tail shield of a tunnel boring machine (Shou et al., 2010; Sterling, 2020).

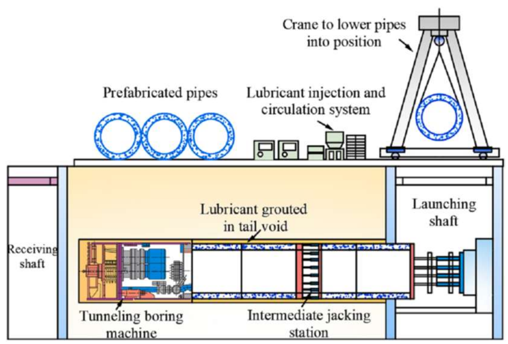

Figure 1. Schematic Illustration of the Pipe Jacking Method
Sources: (Ma et al., 2023)

2.2. Work Breakdown Structure (WBS) Microtunneling Construction Project

The Project Management Institute (PMI) defines the Work Breakdown Structure (WBS) as “a hierarchical decomposition of the total scope of work to be carried out by the project team in order to accomplish the project objectives and create the required deliverables.” The WBS organises and defines the total project scope and represents the work specified in the currently approved project scope statement. In other words, the primary objective of the WBS is to present the project work scope completely and accurately. The highest level of the WBS hierarchy represents the entire project. It is subsequently decomposed into smaller components, each describing the tasks required to complete the higher-level element. This decomposition process continues until the tasks can no longer be subdivided further (or it is no longer considered practical to do so). (Torkanfar & Rezazadeh Azar, 2020).

The Work Breakdown Structure (WBS) of Microtunnelling Construction Project X is presented in Figure 2.

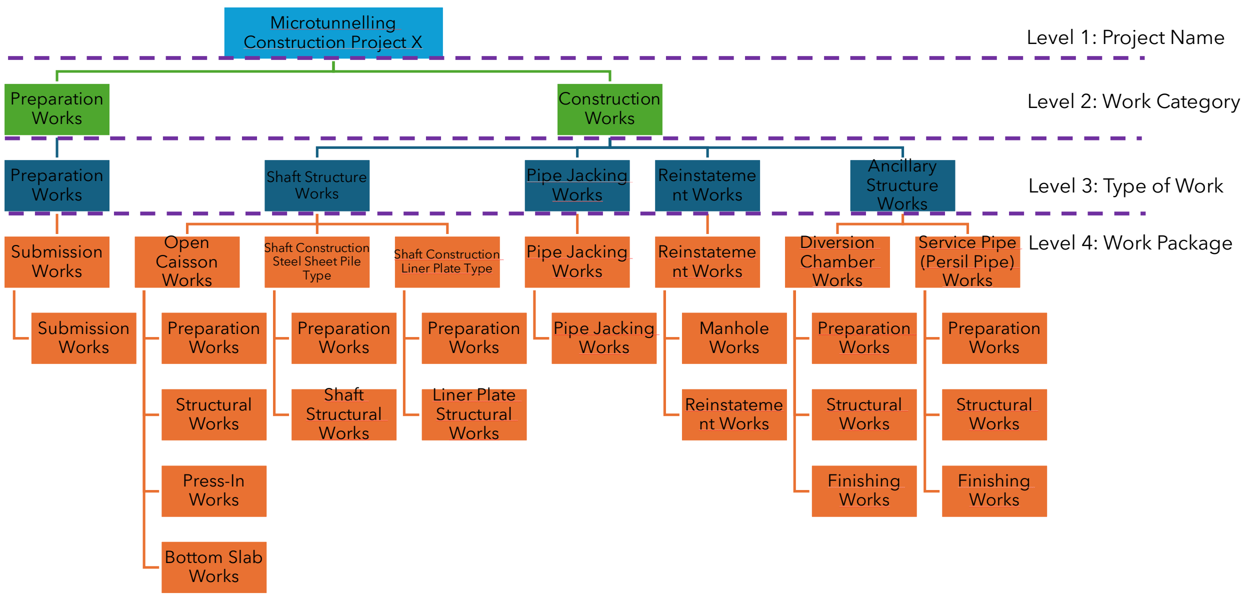

Figure 2. WBS Microtunneling Construction Project X
Sources: (Dokumentasi Proyek JSDP Paket 3, 2024)

2.3. Risk Management Microtunneling Construction Project

Tunnel construction is one of the project types characterised by significant risk, given that execution is carried out underground and involves various factors that must be carefully anticipated. Natural causes of accidents in mechanised tunnel excavation include unfavourable hydrogeological conditions, the presence of groundwater, high rainfall intensity, soft soil strata, and other related factors (Mauretta et al., 2020). Tunnel construction projects are inherently associated with a high level of risk, largely attributable to the variability and inherent unpredictability of geological conditions (Klein & O'Carroll, 2017). Tunnel construction projects frequently encounter situations in which unforeseen conditions threaten the continuity of project execution (Fouladgar et al., 2012).

The following presents a summary of the Risk Breakdown Structure (RBS) for microtunnelling construction projects, as identified in previous studies.

Table 2. Risk Breakdown Structure (RBS) Microtunneling Construction Project

Level 1	Level 2	Reference
Geotechnical Condition Risk	Geological aspect	[1], [2], [3], [4], [5], [6], [7]
	Poor geotechnical survey	[4], [7]

Level 1	Level 2	Reference
Site Condition Risk	Limited response capability due to a confined working environment	[4]
	Poor surface investigation prior to work	[4]
Groundwater	Excessive groundwater inflow	[4]
	Extra Dewatering work	[4]
Tunnel Condition Risk	Machinery aspect	[5], [1], [2], [7], [3]
Actual construction	Scheduling is not following the plan	[4]
	Selection of an inappropriate construction method	[4]
	Technical aspect	[2], [4], [5], [1], [8],
Dense Urban Area Risk	Settlement	[9]
	Traffic	[9]
	Building Impact	[10]
Administration	Delay in sanctioning various permits for tunnel construction from the authorities	[4],
Design	Technical error in Design	[4], [7]
	Delays in design changes	[4]
Management Condition Risk	Human aspect	[2], [3], [3], [4], [8]
	Experience of workers	[7]
	Top Management Policies and Decision	[4]
	Project Manager competence	[4]
	Contractor's experience	[7]
Faults in contracting	Site Conditions not as predicted in the contract	[4]
	Changes in legislation, policies, and regulations	[4]
External Condition Risk	Facility aspect	[5], [2], [1],
	Place of construction	[7]
	Project duration	[7]
	Country of construction	[7]
Social & Political Condition Risk	Political and legal aspects	[2],
	Procurement	[7]
Miscellaneous	Other aspect	[2], [5]
	Act of God	[4]
Construction Safety Aspect	Human factors	[8]
	Materials factors	[8]
	Geological exploration design	[8]
	Technical management	[8]
	Safety management	[8]
	Natural environment	[8]
	Tunnel construction accident	[8]
Breakthrough Risk	Thrust and Reception Shaft Installation	[11]
	Machine Setup and Break-in	[11]

Level 1	Level 2	Reference
	Machine Progression and Lining Placement	[11]
	Machine Breakout and Removal	[11]

Sources: [1]: (Chung et al., 2021), [2]: (Koohathongsumrit & Meethom, 2024), [3]: (Mauretta et al., 2020), [4]: (Shelake et al., 2022), [5]: (Sharafat et al., 2021), [6]: (Arbabsiar et al., 2020), [7]: (Koseoglu Balta et al., 2021), [8]: (Yang et al., 2023), [9]: (Zeng et al., 2023), [10]: (Guo et al., 2024), [11]: (Eid et al., 2023)

3. METHODOLOGY

3.1. Research Design

The objective of this study is to identify risks associated with critical activities in microtunnelling construction works. Critical activities are identified through secondary data collection, including historical data from Project X and three archival datasets from similar projects with comparable primary deliverables. The project archival data utilized in this study consisted of the Construction Programme (Revision 5) for Package 3: Construction of Sewers in Area 1–2, Jakarta Sewerage Development Zone 1 (Kumagai-Wika-Jakon JV, 2025a), as well as construction method documentation describing the execution procedures for each activity, published in 2024 (Kumagai-Wika-Jakon JV, 2024) and 2025 (Kumagai-Wika-Jakon JV, 2025b) for the same project. The historical data utilized in this study consisted of the following:

1. The Base Programme Schedule for the Construction of Sewers in Pilot Area (IP-581), published in 2023 (PT. Waskita Karya, 2023a), along with the work method documentation presented during the pre-construction meeting for the same project (PT. Waskita Karya, 2023b),
2. The project schedule and work method documentation for the Design–Build Package of the Jatiluhur Regional Water Supply System (SPAM), as documented in the approved Project Work Plan issued in 2022 (Wika-Jaya Konstruksi KSO, 2022),
3. The Construction Programme (Revision 6) for Package 2: Construction of Sewers in Area 1–1, Jakarta Sewerage Development Zone 1 (IP-581) (Kumagai-Wika-Jakon JV, 2025c).

Subsequently, content construction is conducted to identify the critical activities that may occur in microtunnelling projects. The identification of risk factors associated with these critical activities is conducted using an expert-judgment approach, supported by questionnaires and interviews. The results of the expert judgment process provide a comprehensive identification of risk factors associated with critical activities in microtunnelling construction works.

3.2. Research Object

The object of this study is microtunnelling construction projects. This research focus is selected because the Indonesian Government allocates annual budgets for wastewater microtunnelling construction to meet the increasing demand for sanitation infrastructure, particularly wastewater pipeline networks in major urban areas. The budget allocation for the domestic wastewater management system under the Directorate General of Human Settlements, Ministry of Public Works, amounted to IDR 2.5 trillion in 2024 (Kementrian Pekerjaan Umum, 2024). The initial contract value of the project examined in this study, namely JSDP Package 3, amounted to IDR 1.29 trillion and JPY 4.22 billion (excluding taxes) (Dokumentasi Proyek JSDP Paket 3, 2024).

3.3. Research Process

The list of critical activities derived from the content construction process will be further validated through questionnaires and interviews with experts to identify and confirm the risk factors that make an activity critical.

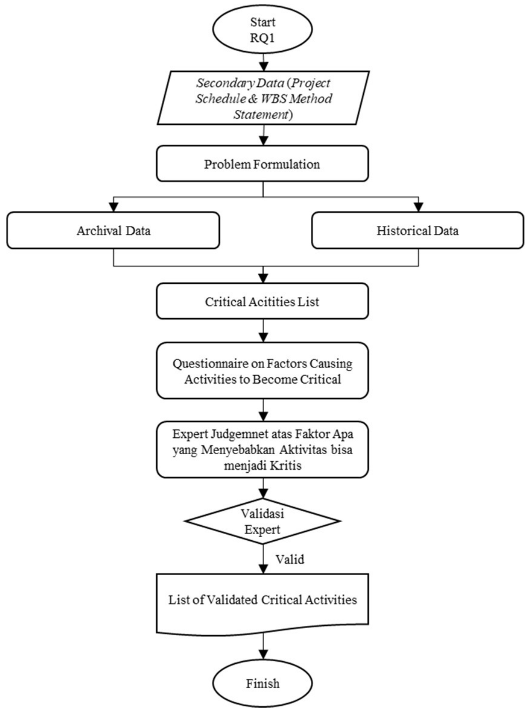

Figure 3. Research Methodology Flow
Sources: (Author's Analysis, 2025)

3.4. Expert

This study involves three experts with experience in executing microtunnelling projects. These experts were selected based on their professional roles, classified as key personnel responsible for project completion. Specifically, practitioners on the contractor side were required to hold at least a managerial position. In contrast, those on the supervision consultant side were required to hold at least a principal expert position. The selected experts have at least 15 years of experience in infrastructure construction projects and demonstrate a high level of professionalism and expertise. In addition, educational qualifications constitute an important criterion, with a minimum requirement of a bachelor's degree in civil engineering or construction management.

4. RESULTS & DISCUSSION

Based on secondary data, including historical data from Project X and three archival datasets from similar projects with comparable primary deliverables, a common logical workflow has been identified. This workflow is summarised and analysed in the table below.

Table 3. Summary of Similarities between Archival Data and Historical Data of Microtunnelling Projects

No.	Item	Similarity
1	Critical Activities	In each archival dataset and historical project data, shaft construction works and pipe jacking operations consistently emerge as critical activities that determine the project completion duration path.
2	Scope of Work Deliverables	Across all archival and historical datasets, the scope of work deliverables can generally be categorised into the following: • Permitting Works • Administrative Works • Preparation Works • Shaft Construction Works

No.	Item	Similarity
		• Pipe Jacking Works • Manhole Works • Diversion Chamber Works • Reinstatement Works • Testing and Commissioning Works
3	Detailed Work Breakdown Structure (WBS) in the Project Schedule	The breakdown of work packages into detailed activities is applied to tasks with higher levels of complexity, which have a greater potential for delays if not closely controlled, may form part of the critical path, and require detailed monitoring for effective control. Consequently, each project schedule incorporates a level of detail tailored to its specific requirements.

Sources: (Author's Analysis, 2026)

The summary of critical activities in microtunnelling works, along with their locations within specific projects, is presented in the table below. This summary is based on construction schedules and Work Breakdown Structure (WBS) documents, including method statements, from four project datasets.

Table 4. List of Critical Activities in Four Microtunnelling Project Case Studies

No.	List of Critical Activities	Project Reference
1	**Permitting Works**	
1.1	Preparation of Permit Documents	[2]
1.2	PLN Permitting	[2]
1.3	PGN Permitting	[2]
1.4	PAM Jaya Permitting	[2]
1.5	Telkom Permitting	[2]
2	**Preparation Works**	
2.1	**Test Pit Works**	
2.1.1	Data Planning Works (Pipeline Alignment Plan, As-Built Drawings (PDAM, PLN, Telkom), Utility Structure Positions)	[3]
2.1.2	Test Pit Location Determination	[3]
2.1.3	Test Pit Execution	[3]
2.1.4	Pipeline Route Revision (if Changes Occur)	[3]
2.2	Traffic Diversion	[3]
2.3	Fence Installation (6 × 50 m)	[3]
2.4	Soil Disposal Area Preparation	[3]
3	**Shaft Works**	
3.1	**Liner Plate Shaft Construction Works**	
3.1.1	Excavation and Installation of Liner Plate – Stage 1	[2]
3.1.2	Disposal of Excavated Material and Excavation Cleaning	[2]
3.1.3	Installation of Liner Plates – Stage 2 (continuous until reaching design depth)	[2]
3.1.4	Compaction of Subgrade Soil Layer	[2]
3.1.5	Concrete Casting and Surface Levelling of Base Slab	[2]
3.1.6	Soil Backfill Grouting Works	[2]
3.2	**Steel Sheet Pile (SSP) Shaft Works**	
3.2.1	**Vertical Shaft Preparation Works**	
3.2.1.1	Work Permit Activities	[1], [2], [3], [4]
3.2.1.2	Site Hoarding Works	[1], [2], [3], [4]
3.2.1.3	Equipment Setup Works	[1], [2], [3], [4]
3.2.1.4	Survey and Setting-Out Works	[1], [2], [3], [4]
3.2.1.5	Utility and Flood Protection Works	[1], [2], [3], [4]
3.2.1.6	Demolition of Existing Pavement Works	[1], [2], [3], [4]

No.	List of Critical Activities	Project Reference
3.2.2	**Driving of Steel Sheet Piles for Vertical Shaft Construction**	
3.2.2.1	Installation of Guide Line (String Line or Guide Beam) for Alignment Control	[1], [2], [3], [4]
3.2.2.2	Sheet Pile Driving Works	[1], [2], [3], [4]
3.2.2.3	Joint Inspection Works	[1], [2], [3], [4]
3.2.3	**Excavation and Base Preparation for Vertical Shaft**	
3.2.3.1	Excavation Works	[1], [2], [3], [4]
3.2.3.2	Waler Beam Installation Works	[1], [2], [3], [4]
3.2.3.3	Subgrade Preparation at the Bottom of the Jacking Shaft	[1], [2], [3], [4]
3.2.3.4	Concrete Casting at the Bottom of the Jacking Shaft	[1], [2], [3], [4]
3.3	**Open Caisson Construction Works**	
3.3.1	**Open Caisson Structural Works**	
3.3.1.1	Inside and outside scaffold installation	[1]
3.3.1.2	Rebar installation	[1]
3.3.1.3	Formwork installation	[1]
3.3.1.4	Concrete placing work	[1]
3.3.1.5	Curing work	[1]
3.3.1.6	Dismantling of inner formwork	[1]
3.3.1.7	Dismantling of outer formwork	[1]
3.3.1.8	Formwork removal	[1]
3.3.2	**Press-In and Excavation Works Open Caisson**	
3.3.2.1	Excavation and press-in sinking in caisson work	[1]
3.3.2.2	Completion of press-in sinking work	[1]
3.3.2.3	Removal of press-in equipment	[1]
3.3.3	**Contact Grout Works**	
3.3.3.1	Contact Grout work	[1]
3.3.3.2	Curing work	[1]
3.3.4	**Underwater Concrete Works**	
3.3.4.1	Cleaning of cutting-edge work	[1]
3.3.4.2	Slime processing work	[1]
3.3.4.3	Placing and curing underwater concrete at the bottom of the work	[1]
3.3.5	**Base Concrete Works**	
3.3.5.1	Cleaning inside the caisson work	[1]
3.3.5.2	Bottom slab rebar work	[1]
3.3.5.3	Concrete placement of the bottom slab work	[1]
4	**Pipe Jacking Works**	
4.1	**Preparation Works for Pipe Jacking**	
4.1.1	Preparation Works (Work Permit, Site Hoarding, Equipment Setting-up, Survey, and Setting Out)	[1], [2], [3], [4]
4.1.2	Thrust Wall Construction	[1], [2], [3], [4]
4.1.3	Entry Eye Construction	[1], [2], [3], [4]
4.1.4	Jacking Installation Work – Driving guide rail installation	[1], [2], [3], [4]
4.1.5	Main hydraulic jack installation	[1], [2], [3], [4]
4.1.6	Jacking Machine Setting Work (Setting Gantry, Setting Thrust Block, Setting Guard Rail and Staging, Setting Entrance Ring, Setting Jacking Machine)	[1], [2], [3], [4]
4.1.7	Entry Eye Cutting Work	[1], [2], [3], [4]
4.2	**Pipe Jacking Works**	
4.2.1	Putting jacks back	[1], [2], [3], [4]
4.2.2	Disconnect the slurry pipe	[1], [2], [3], [4]
4.2.3	Disconnect cable	[1], [2], [3], [4]
4.2.4	Jacking pipe setting	[1], [2], [3], [4]
4.2.5	Slurry pipes connection	[1], [2], [3], [4]
4.2.6	Cable connection	[1], [2], [3], [4]
4.2.7	Pipe connection	[1], [2], [3], [4]

No.	List of Critical Activities	Project Reference
4.2.8	Jacking pipe jacking in	[1], [2], [3], [4]
4.3	**Arrival Pipe Jacking Works**	
4.3.1	Exit eye construction	[1], [2], [3], [4]
4.3.2	Arrival guide rail installation	[1], [2], [3], [4]
4.3.3	Jacking machine removal work	[1], [2], [3], [4]
4.3.4	In-pipe equipment removal work	[1], [2], [3], [4]
4.3.5	Backfilling injection work	[1], [2], [3], [4]
4.3.6	Pipe cleaning & pipe joint treatment work	[1], [2], [3], [4]
5	**Manhole Works**	
5.1	**Precast Manhole Works**	
5.1.1	Installation of Shaft Sections	[2]
5.1.2	Installation of RC Converter Slab	[2]
5.1.3	Installation of RC Make-Up Ring	[2]
5.1.4	Installation of RC Cover	[2]
5.2	**Cast-in-Situ Manhole Works**	
5.2.1	Preparation Works	[1]
5.2.2	Construction / Casting of Base Slab	[1]
5.2.3	Installation of Connecting Pipes	[1]
5.2.4	Construction of Walls and Slabs for the First Layer	[1]
5.2.5	Protective Concrete Works for RC (Reinforced Concrete) Jacking Pipes	[1]
5.2.6	Initial Backfilling and Compaction	[1]
5.2.7	Continuation of Wall and Slab Construction up to the Top Slab	[1]
5.2.8	Construction of Invert Concrete (Channel Base)	[1]
5.2.9	Epoxy Coating Works	[1]
5.2.10	Installation of Precast Manhole Units	[1]
5.2.11	Backfilling and Compaction to Completion	[1]
6	**Diversion Chamber Works**	
6.1	**Preparation Works Diversion Chamber**	
6.1.1	Submission for Preparation Works	[4]
6.1.2	Preparation works approval	[4]
6.1.3	Test pit	[4]
6.1.4	Utility identifies Diversion Chamber	[4]
6.2	**Construction Works Diversion Chamber**	
6.2.1	SSP driving & Excavation 1st Stage	[4]
6.2.2	Divert Existing Drainage	[4]
6.2.3	Demolish Existing Drainage	[4]
6.2.4	Excavation 2nd Stage	[4]
6.2.5	Diversion Chamber	[4]
6.2.6	Inflow PIT	[4]
6.2.7	Pipe installation	[4]
6.2.8	Extraction SSP	[4]
7	**Reinstatement Works**	
7.1	Preparation Works	[1], [2], [3], [4]
7.2	Rehabilitation of Asphalt Pavement (Surface Course (AC-WC), Tack Coat) and Rigid Pavement (Concrete)	[1], [2], [3], [4]
7.3	Rehabilitation of Paving Block Pavement (Sidewalk)	[1], [2], [3], [4]
7.4	Restoration of Green Areas or Open Spaces	[1], [2], [3], [4]
7.5	Dismantling of Project Hoarding	[1], [2], [3], [4]
7.6	Road Marking Works	[1], [2], [3], [4]
8	**Administrative Works**	
8.1	Submission of As-Built Drawing	[2]
8.2	Preparation of MC-100 (Final Measurement Certificate)	[2]
9	**Testing and Commissioning Activities**	[2]

Sources:
[1]: Achival data construction project Microtunelling JSDP Paket 3 (Kumagai-Wika-Jakon JV, 2025a),
[2]: Historical data Construction of Sewers in Pilot Area (IP-581) Paket 4 Zona 1 (PT. Waskita Karya, 2023a),
[3]: Historical data construction project Paket Rancang Bangun SPAM Regional Jatiluhur (PT. Wijaya Karya, 2022),
[4]: Historical data Construction of Sewers in Area 1-1 Jakarta Sewerage Development Project (Zone 1) (IP-581) Paket 2 Zona 1 (Kumagai-Wika-Jakon JV, 2025c).

Identifying critical activities in microtunneling project management is essential because they lie on the critical path, which determines the overall project duration. Any delay in a critical activity will delay completion of the entire project. Potential risks associated with critical activities must be properly mitigated and managed to ensure that any arising risks can be effectively controlled and their impact on project performance minimised.

Subsequently, after obtaining the list of critical activities, questionnaires and interviews were conducted with experts to identify the factors contributing to their criticality. Each expert was asked to evaluate every identified critical activity through the following question: “Based on your experience and professional judgment, what factors could cause this activity to become critical?” Experts were then requested to identify and explain the risk factors associated with each critical activity. Specifically, they were asked to identify risks that could affect the activity and delay its execution. The responses provided by the experts could be similar or different across individuals, reflecting their respective experiences and perspectives. These responses constituted the primary data used to identify and analyze the risk factors associated with each critical activity.

The next step involved consolidating and synthesizing the experts' opinions through content analysis. This analysis enabled the identification of a risk pool for each critical activity, ranging from permitting works to testing and commissioning activities. Through this research process, the study successfully identified the critical activities in microtunneling projects and the associated risks for each. The resulting risk pools provide a comprehensive understanding of the factors that may affect the timely execution of critical project activities and, consequently, the overall project schedule.

The resulting conclusions, in the form of primary data on risk identification, are presented in the table below.

Table 5. Risk Pool for Critical Activities Permitting Works

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
1	**Permitting Works**			
1.1	Preparation of Permit Documents	Administrative Risk	X1	The permitting process is not completed on time due to procedural complexity and the requirement for comprehensive documentation.
			X2	Limited coordination time with relevant permitting authorities results in additional delays in permit processing.
			X3	The revision process of administrative permitting documents cannot be completed promptly.
			X4	Bureaucratic procedures within authorities or other relevant institutions require considerable time to grant approvals.
1.4	PAM Jaya Permitting	Administrative Risk	X15	Approval from external stakeholders for work carried out in proximity to utility assets at the project site requires

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
				significant time to fulfil administrative requirements, including discussions, data collection, and obtaining recommendations or work permits.
			X16	The permitting process is not completed on time due to procedural complexity and the requirement for comprehensive documentation.
			X17	Bureaucratic approval stages within authorities or other institutions require an extended processing time.
		External Condition Risk	X18	Limited time and human resources available to utility owners to conduct joint inspections with the executing contractor constrain the completion of permitting procedures.
			X19	The construction work area conflicts with existing utility placements, necessitating additional relocations of those utilities.

Sources: (Author's Analysis, 2026)

Permit-related activities are subject to several risk factors, including the complexity of the process and the requirement for comprehensive documentation, bureaucratic procedural issues, limited availability of personnel in charge within the permitting authorities, and conflicts with existing utilities. If these risks are not effectively controlled, certain project activities that require prior permit approval cannot proceed as planned, resulting in delays to project execution and extending the overall project completion time.

Table 6. Risk Pool for Critical Activities: Excavation Shaft Work SSP Type

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
3	**Shaft works**			
3.2	**Steel sheet pile shaft works (SSP type)**			
3.2.3	**Excavation and base shaft, vertical shaft work**			
3.2.3.1	Excavation works	Geological risks.	X136	Slope failure or structural failure caused by soil instability.
			X137	High groundwater table conditions reduce construction productivity.
			X138	Very poor soil conditions reduce the effectiveness of equipment utilisation.
		Technical risks.	X139	Construction productivity decreases as work is carried out at greater depths.
		Country-related risks at the construction location.	X140	A shortage of construction equipment due to limited availability, as the equipment is simultaneously deployed across multiple ongoing projects.
3.2.3.2	Waller beam installation works	Geological risks.	X141	Very poor soil conditions reduce the effectiveness of equipment utilisation.
			X142	Slope failure or structural failure caused by soil instability.

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
		Country-related risks at the construction location.	X143	A shortage of skilled human resources capable of performing work in accordance with the quality specifications required by the contract.
3.2.3.3	Subgrade preparation works for the bottom of the jacking shaft	Geological risks.	X144	Slope failure or structural failure caused by soil instability.
			X145	High groundwater table conditions reduce construction productivity.
		Technical risks.	X146	Construction productivity decreases as work is carried out at greater depths.
		Country-related risks at the construction location.	X147	Required materials are not readily available in stock
3.2.3.4	Concrete casting works for the bottom of the jacking shaft	Safety risks related to human factors.	X148	Workplace accidents often stem from an insufficient understanding of operations in confined spaces or activities involving elevation differences.
		Construction site location risks.	X149	Restricted working space in a confined area
		Geological risks.	X150	High groundwater levels reduce construction productivity

Sources: (Author's Analysis, 2026)

The activities of excavation and base shaft construction, vertical shaft construction, and steel sheet pile shaft installation are subject to geological risk factors related to soil stability, ground conditions, and groundwater levels. If these risks are not effectively controlled, the retaining structures may experience failure or collapse, requiring corrective actions and additional time for remediation. Consequently, work productivity decreases, extending the overall project duration. Another significant risk aspect is technical risk, particularly related to excavation depth. If the required equipment and supporting resources are not adequately provided, productivity may decline, resulting in delays to project execution. In addition, country-related risks at the construction site include shortages of construction equipment, limited availability of skilled labour, and insufficient material readiness. These constraints can limit the availability of critical resources, causing actual productivity to fall below the levels assumed in the project plan and ultimately affecting the project schedule.

Table 7. Risk Pool for Critical Activities: Press-in and excavation works, Shaft Work, Open Caisson Type

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
3	**Shaft works**			
3.3	**Open caisson works**			
3.3.2	**Press-in and excavation works for the open caisson**			
3.3.2.1	Excavation and press-in sinking in caisson work	Geological risks.	X178	Slope failure or structural failure caused by soil instability.
			X179	Hard soil conditions reduce construction productivity.
		Technical errors in design pose risks.	X180	*Unforeseen* differences between the soil investigation data obtained during the site investigation and the actual field conditions.

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
		Construction method selection risks.	X181	The planned construction method is ineffective under the existing site conditions.
		Country-related risks at the construction location.	X182	A shortage of specialised subcontractors for work with specific technical requirements due to the limited number of qualified providers available.
3.3.2.2	Completion of press-in sinking work	Geological risks.	X183	Hard soil conditions reduce construction productivity.
		Technical errors in design pose risks.	X184	*Unforeseen* differences between the soil investigation data obtained during the site investigation and the actual field conditions.
		Construction method selection risks.	X185	The planned construction method is ineffective under the existing site conditions.
		Country-related risks at the construction location.	X186	A shortage of specialised subcontractors for work with specific technical requirements due to the limited number of qualified providers available.
3.3.2.3	Removal of press-in equipment	Country-related risks at the construction location.	X187	A shortage of specialised subcontractors for work with specific technical requirements due to the limited number of qualified providers available.
			X188	A shortage of construction equipment due to limited availability, as the required equipment is owned only by a small number of specialised subcontractors.
		Construction method selection risks.	X189	Limited availability of equipment due to sequencing methods and interdependencies with preceding or subsequent activities affects the project cost budget.

Sources: (Author’s Analysis, 2026)

The press-in and excavation works for the open caisson are exposed to several risk factors. One of the primary risks is associated with hard soil conditions, which can significantly reduce construction productivity. In addition, technical design risks, particularly unforeseen discrepancies between the actual ground conditions and the soil investigation data, may adversely affect the construction process. These risks can result in the caisson structure requiring a longer duration during the press-in operation than originally planned. Another important risk category is country-related risks at the construction location, specifically the shortage of specialised subcontractors. If delays occur in these activities, it is often difficult to mobilise additional equipment and manpower because the work requires specialised expertise and equipment that are available only in limited numbers. Consequently, the lack of readily available resources can prolong the delay and negatively impact the overall project schedule.

Table 8. Risk Pool for Critical Activities Pipe Jacking Installation Works

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
4	**Pipe jacking works**			
4.2	**Pipe jacking installation works**			

ID	List of Critical Activities	Risk Category	Variabel X	Risk Factor
4.2.8	Jacking pipe jacking in	Country-related risks at the construction location.	X256	A shortage of specialised subcontractors for work with specific technical requirements due to the limited number of qualified providers available.
		Safety risks related to human factors.	X257	A shortage of specialised subcontractors for work with specific technical requirements due to the limited number of qualified providers available.
		Construction site location risks.	X258	Restricted working space in confined areas limits construction activities.
		Geological risks.	X259	Hard soil conditions reduce construction productivity.
			X260	Hard soil conditions reduce construction productivity.
		Unforeseen site condition risks are inconsistent with contractual assumptions.	X261	Unforeseen subsurface conditions encountered during excavation that are incompatible with the specifications of the equipment used.
		Construction method selection risks.	X262	The equipment used does not perform effectively under the existing actual site conditions.

Sources: (Author's Analysis, 2026)

The pipe jacking installation works are subject to several significant risk factors. One of the major risks is the shortage of specialised subcontractors for work involving specific technical requirements. If disruptions occur during construction, implementing corrective measures may be challenging because both the required equipment and the skilled personnel to operate it are in limited supply within the host country. This limitation can hinder recovery efforts and prolong project delays. Another critical risk factor is the presence of hard soil conditions, which can reduce construction productivity and prevent the optimal utilisation of pipe jacking equipment. As a result, the efficiency of the installation process may decline, leading to schedule overruns. Furthermore, one of the most significant risks is the presence of unforeseen subsurface conditions, such as buried timber piles (dolken), mini piles, fossils, archaeological artefacts, or other obstructions that the jacking machine cannot fragment. These unexpected obstacles may cause the jacking machine to jam or cease operating entirely. In addition, machine components may suffer damage, requiring repair or replacement. Consequently, construction activities may be interrupted, resulting in substantial delays to the overall project completion schedule.

5. CONCLUSION

This study successfully identified the critical activities in microtunneling projects and the risk factors that may render these activities critical. Based on project document analysis and validation by industry experts through questionnaires and interviews, the study identified a number of critical activities across all project phases, including Permitting Works, Preparation Works, Shaft Works, Pipe Jacking Works, Manhole Works, Diversion Chamber Works, Reinstatement Works, Administrative Works, and Testing and Commissioning Activities.

This study also successfully identified a range of risks associated with each critical activity. These risks include permitting process complexity, bureaucratic procedural issues, conflicts with existing utilities, geological conditions related to subsurface soil characteristics and groundwater levels, shortages of specialized skilled labor, limited availability of jacking equipment, unforeseen discrepancies between actual ground conditions and soil investigation data, and unforeseen subsurface obstructions, such as buried timber piles (dolken), mini piles, fossils, archaeological artifacts, or other objects that cannot be fragmented by the jacking machine. In addition, various other construction-related issues were identified as potential sources of project risk. If these risks are not effectively mitigated and managed, delays may occur in critical activities. Since critical activities lie on the project's critical path, any delay in these activities can directly affect the overall project schedule and ultimately delay project completion.

The findings of this study provide a comprehensive understanding of the critical activities and their associated risks that may potentially lead to project delays. These findings can serve as a valuable reference for project managers and construction company management in developing effective risk management and mitigation strategies. By proactively identifying and addressing these risks, stakeholders can minimize their potential impacts and increase the likelihood of completing microtunneling projects on schedule.

5.1. Practical Implication

The critical activities identified in this study can serve as a reference for similar microtunnelling construction projects. In this study, the critical activities, categorised by work type, include permitting works, preparation works, shaft works, pipe jacking works, manhole works, diversion chamber works, reinstatement works, administrative works, and testing and commissioning works. Furthermore, this study identifies the risk factors influencing each critical activity, enabling similar projects to implement early mitigation measures, undertake preventive actions before risks materialise, and establish appropriate reactive measures if such risks materialise.

5.2. Limitations and Future Research

This study focuses solely on installing wastewater pipeline networks using the microtunnelling pipe-jacking method. From a broader perspective, wastewater sanitation management encompasses not only the installation of pipeline networks but also the construction of wastewater treatment plants. Therefore, future research may be directed toward identifying risk factors and corresponding mitigation strategies for the construction of wastewater treatment plants that were not addressed in this study.

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